European Commission

Proceedings of the 7th International Conference EEDAL'2013 Energy Efficiency in Domestic Appliances and Lighting

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JOINT RESEARCH CENTRE

2014

Report EUR 26660 EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Energy and Transport

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JRC 89810

EUR 26660 EN

ISBN 978-92-79-38406-6

ISSN 1831-9424

doi: 10.2790/2313

Luxembourg: Publications Office of the European Union, 2014

Printed in Italy

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Introduction

Citizens and households are responsible for a large share of global energy and electricity consumption and the related greenhouse gas emissions into the atmosphere. Residential energy demand is also rapidly increasing, due to a higher degree of basic comfort and level of amenities: larger homes, new services and new appliances and equipment (in particular information and communications technology, ICT), which is putting a strain on the economies and energy infrastructures of both developed and developing countries.

Energy efficiency improvements in *residential appliances, heating and cooling equipment, ICT equipment and lighting* can play a key role in achieving a sustainable energy future and socio-economic development, and at the same time mitigate climate change. Energy efficiency measures related to residential appliances, heating equipment and lighting are in most cases highly cost-effective CO_2 emission reduction actions, and offer good opportunity to increase the security and reliability of energy supply. In developing countries efficient residential appliances and lighting are vital to reduce household energy costs, to improve living conditions while reducing local pollution. In addition to technical progress on efficiency, large energy savings and carbon reduction can only be achieved with a paradigmatic change in consumer behaviour in the context of usage patterns of energy using products. These changes must be aided by “smart” product design providing automatic optimisation of energy and water resource usage for a given task and providing readily accessible feedback to the consumer to catalyse optimum usage patterns.

These themes are echoed in a growing number of *policy commitments* and in strategies calling for action at local, regional, national and global levels. The challenge, now, is to ensure market, policy, trade and information barriers do not impede the timely development, delivery and proper use of energy efficient residential equipment, resulting in a missed opportunity for climate change mitigation, security of energy supply and socio-economic development, particularly considering the present global economy. Last, but not least, the consumer must accept these changes and not misuse energy saving on one side by energy consumption for other purposes.

In addition, *smart appliances* and equipment, *smart meters* and communication protocols, allow households to be a key part of the *smart grids*, with storage, load flexibility and generation capabilities through renewable energies and *demand response and system energy savings*.

The international community of stakeholders dealing with residential appliances, equipment, metering and lighting (including manufacturers, retailers, consumers, governments, international organisations and agencies, academia and experts) have already gathered six times at the **International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL)** (Florence 1997, Naples 2000, Turin 2003, London 2006, Berlin 2009, Copenhagen 2011) to discuss the progress achieved in technologies, behavioural aspects and policies, and the strategies that need to be implemented to further progress this important work.

The previous EEDAL conferences have been very successful in attracting an international audience, representing a wide variety of stakeholders involved in policy implementation and development, as well as the manufacturing and promotion of energy efficient residential appliances and lighting. The EEDAL conference has established itself as an influential and recognised international event where participants can discuss the latest developments, establish synergies and build international partnerships among stakeholders.

Following the success of the previous EEDAL conferences, the University of Coimbra and the European Commission Joint Research Centre, in collaboration with the United Nations Development Programme, the International Energy Agency, and the Collaborative Labeling and Appliance Standards Program (CLASP), organised the 7th International Conference on Energy Efficiency in Domestic Appliances and Lighting – EEDAL'13, 11-13 September 2013, in Coimbra, Portugal

EEDAL'13 provided a unique forum to discuss and debate the latest developments in energy and environmental impact of residential appliances and lighting, heating and cooling equipment, ITC equipment, smart meters and smart grids, consumer behaviour, the policies and programmes adopted and planned, as well as the technical and commercial advances in the dissemination and penetration of technologies and solutions, particularly: energy efficient residential appliances, consumer electronics and ICT, heating and cooling equipment and lighting.

The three-day conference included plenary sessions where key representatives of governments and international organisations, manufacturers and academia presented their views and programmes to advance energy efficiency in residential appliances and lighting, for example, through international co-operation on product information and eco-design requirements. Parallel sessions on specific themes and topics allowed in-depth discussions among participants. The conference also hosted ad-hoc workshops to review and advance international collaboration and provided opportunities strengthen existing and promote new initiatives and partnerships.

Improving confidence of evaluation of energy savings through international standards[1]

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Abstract

Several regions and organizations have standardized the evaluation of energy savings with different objects and diverse technical perspective. In 2008, ISO (International Organization for Standardization) and IEA worked together to identify standardized methodologies for the calculation of energy savings. International standards were proposed to harmonize the framework, principles and methodologies of evaluation of energy savings. In 2010, ISO decided to establish a new Technical Committee (ISO/TC 257, Energy savings) to start the development of international standards for determining energy savings in three categories: regions, organizations and projects. This paper presents the working program and newest progress of the international standards in this new technical field. The impact of the standards on stakeholders including policy-makers, evaluators, ESCOs and energy-using organizations will be discussed. The implementation of international standards combined with validation mechanisms may enhance the adoption of these standards and the paper discusses ways to implement these standards. The authors will also discuss the key factors which may affect successful implementation of these standards.

Introduction

In recent years, concerns about rising energy demand and climate change have greatly affected global energy-related practices. Both suppliers and users of energy resources now have to work toward conservation and increasing efficiency. Energy savings and resulting improvement of energy efficiency are the most effective ways to restrain energy consumption and reduce greenhouse gas (GHG) emissions. Without energy savings and the progress made in energy efficiency since 1973, total energy consumption of OECD countries would have been 63% higher than at present. Further, IEA analysis shows that, for a group of 17 IEA countries (the IEA 17), total final energy consumption would have been 17% higher in 2006. According to this trend, it means IEA 17 has saved energy of 20 EJ in 2004.[1] More recently, the IEA and the IPCC 2007 Working Group III identified energy efficiency's significant potential to reduce GHG emissions over the next 20 to 30 years. [2]

IEA analysis shows many barriers to energy efficiency affect all economic sectors. These obstacles include uninformed investors with little familiarity with energy-efficient products and the difficulty of quantifying external benefits. As a result, it is important to coordinate policies in a way that addresses all of these barriers, across all sectors. As a cross-sector recommendation, it is recommended to develop measurement and verification protocols to ensure consistency in methodology, overcome uncertainties in quantifying the benefits of energy efficiency investments, and stimulate increased private-sector involvement. The total potential energy savings by sectors per year by 2030 may reach 82.1 EJ. (Fig. 1)

[1] Project 201210231 supported by Special Fund for Sector Research in the Public Interest.

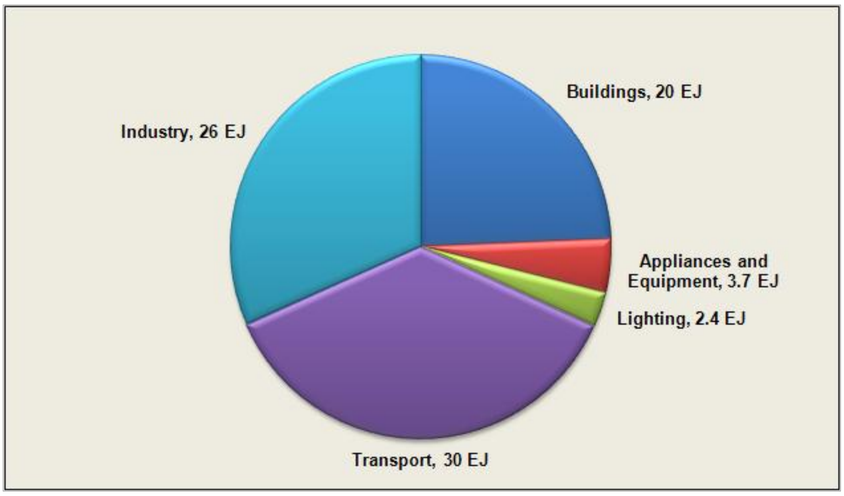

Figure 1 Potential energy savings from energy efficiency by sector per year by 2030[3]

Energy utilities play an important role in promoting energy efficiency. Utility activities to promote energy efficiency often combine a requirement to meet energy efficiency with the use of market-based instruments to enable utilities to trade savings obligations and to allow competition in the delivery of energy services towards savings targets. Through properly structured programs, utilities can recover costs and maintain revenues and profits by sharing the costs and benefits with the final consumer. This gives utilities a large incentive to ensure energy savings are delivered at least cost.[3] Energy savings and the resulting improved energy efficiency are the best ways to restrain energy consumption and reduce GHG emissions. The gains could be huge: total potential energy savings could reach 82.1 EJ by 2030, exceeding the annual electricity consumption in 2009 of China, Japan and the USA combined.

Measurement, calculation and verification have established themselves as the cornerstone to stimulate technologies and policies and encourage efficiency. According to the IEA, when determining energy savings it is important to ensure consistency in methodology; overcome uncertainties in quantifying the benefits of investments; and stimulate increased private-sector involvement.[4]

International standards are recognized as efficient tools to reduce uncertainty for all economic players. Technical consensus supports international trade and the development of new markets. Standards are also valuable in improving consumer understanding and confidence, which influences behaviour and choices. Technical standards to evaluate energy savings are not limited to the measurement of performance metrics; other standards in the field help in monitoring, identifying and verifying energy savings delivered via a range of programs. The adoption of these broader standards contributes to the development of more fungible and international energy efficiency markets, bringing us closer to the day when energy savings can be bought and sold as commodities in the same way electricity and gas are currently traded.

The standardization of energy savings is actually not an entirely new field, but has been carried out globally for two decades. As part of its national energy conservation plan, China has worked since the 1990s to develop and revise its national standards GB/T 13234, Method of calculating energy saved for enterprises (first published in 1991), and GB/T 13471s, Methods for calculating and evaluating the economic value of electricity saving measures (first published in 1992). The US Department of Energy (DOE) began working with industry in early 1994 to develop a consensus approach to measuring and verifying efficiency investments with the aim of overcoming existing barriers to efficiency. The North American Measurement and Verification Protocol (NEMVP) was published in 1996. The second version of the protocol renamed the International Performance Measurement and Verification Protocol (IPMVP), was published in 1997. A growing number of energy efficiency services companies are adopting the IPMVP, which is maintained by the Efficiency Valuation Organization (EVO) to measure and verify energy savings. In Europe, the European Union’s Energy End-use Efficiency and Energy Services Directive (2006/32/EC) calls for the development of harmonized measurement and verification methods for energy savings. South Africa has also taken steps toward development of a national standard for measurement and verification of energy savings. Internationally, the IEA has plans to evaluate energy savings policies worldwide.

Development of ISO standards

In 2007, ISO and the IEA recognized the need for an International Standard to promote energy efficiency and a shift to renewable sources. The two organizations agreed that the new standard should harmonize terminology and calculation methods for energy efficiency, consumption and savings, as well as methods and criteria to calculate energy yield of various primary energy sources.

In September 2010, the ISO Technical Management Board approved the creation of ISO technical committee ISO/TC 257, Energy savings, to develop the ISO standard. The scope of ISO/TC 257 is: Standardisation in the field of energy savings through general technical rules and specific methodologies for the calculation of energy savings in projects, organizations and regions, and guidance on measurement, verification, and assessment of data quality as it relates to these calculations. This TC is actively involved in developing the basic standards for determining energy savings in projects, organizations and regions; and providing effective tools, including quantitative methodologies, to enable stakeholders to better define, adopt, manage and improve technical and management measures to achieve energy savings and increase energy efficiency.

Working framework of ISO/TC 257

The main purpose of the new standards being developed by ISO/TC 257 is to facilitate the harmonization of national standards, specifications and requirements for determination of energy savings. Building on international practices and experiences, the upcoming ISO standards will target different levels, such as project level, enterprise level and regional level. The essential terminologies, technical rules, methodologies, tools and guidance for measurement, calculation and verification of energy savings may be addressed in different standards. The main work of these standards will include procedures, methodologies, principles, requirements and guidelines.

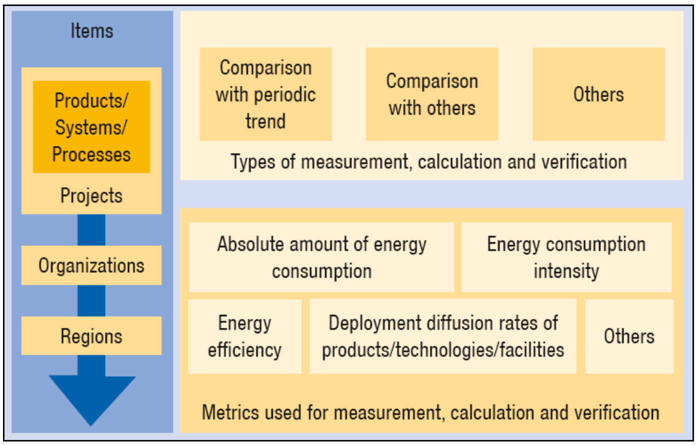

Figure 2 Working framework for measurement, calculation and verification of energy savings[5]

Figure 2 shows the working framework for measuring, calculating and verifying energy savings. According to the working scope, five categories are proposed to promote the development of standards in ISO/TC 257. These are:

- General technical rules
- Guidance on cross-cutting issues
- Methodology for regions

- Methodology for organizations
- Methodology for projects

ISO/TC 257 work programme

Energy savings amount to avoided energy consumption, which means that it cannot be directly measured in practice – a measured difference in energy consumption is often not a real energy savings because underlying conditions may have changed. It is usually necessary to calibrate inputs to determine real energy savings, and multiple methods (for example benchmarking) have been introduced to deal with this issue. Problems arise in evaluation of energy efficiency measures due to different methodologies in the calculation and evaluation methods used internationally. Many countries experience considerable difficulty in evaluating energy efficiency activities because of a lack of relevant International Standards. Transverse rules must be robust in relation to existing innovations in different countries and different fields if the new International Standards are to succeed.

Prior working items include general technical rules and some fundamental methodologies. These subjects will build the framework of principles and essential guidelines for developing special methodologies in different levels of items.

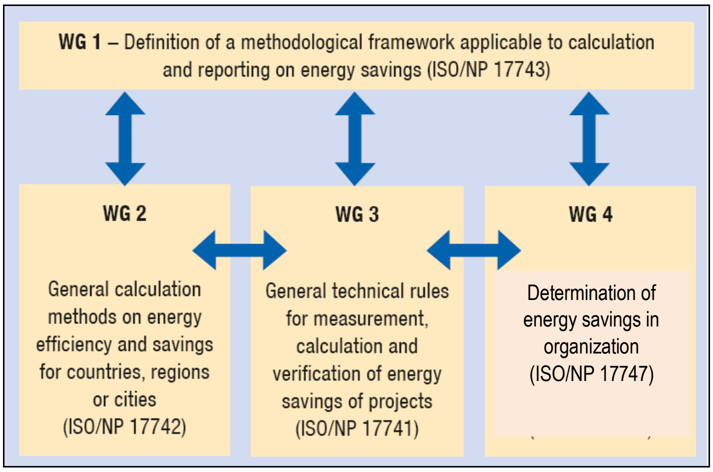

Figure 3 Working program of ISO/TC 257[6]

As shown in Figure 3, there are four standards have already been launched as new work in progress items and approved for registration within ISO/TC 257. The planed timeline for these projects is shown in table 1.

Table 1 planed timeline for ISO/TC 257's projects

Sequence number	Title	Current Stage	Planed published date
17741	General technical rules for measurement, calculation and verification of energy savings for projects	Working draft (WD)	April, 2015
17742	General calculation methods on energy efficiency and savings for countries, regions or cities	The 2nd versions of Committee draft	March, 2015
17743	Definition of a methodological framework applicable to calculation and reporting	The 2nd versions of Committee draft	April, 2015
17747	Determination of energy savings in organizations	Working draft (WD)	September, 2015

Note: Normally, the project of international standard in ISO will go through 5 key stages: New project (NP), Working Draft (WD), Committee Draft (CD), Draft International Standard (DIS) and Final Draft International Standard (FDIS).

More subjects could be developed as International Standards, or as a part of International Standards in ISO/TC 257, to enrich guidelines and tools to develop special methodologies in different levels. Potential additional subjects include: 1) framework and guidelines on measurement, calculation, verification and report of energy savings in energy efficiency services; 2) guidelines for selecting energy savings evaluators; 3) requirements of data quality for quantification of energy savings; 4) guidelines and procedures for analysis of energy savings potential; and 5) guidelines for evaluating and declaring energy savings in procurement of energy efficient products.

Implementation of ISO standards

Users of ISO standards

When used properly, these tools can provide significant advantages and benefits to users in the private and public sectors. As a solid technical foundation for energy savings quantification, ISO/TC 257's work products may create a flourishing market in energy efficiency improvements. For International Standards on this issue, target users may include:

- Organizations quantifying their tally in relation to energy saving projects, installing the equipment and implementing the programmes
- Investors evaluating projects and/or technologies
- Policy-makers evaluating and quantifying the energy savings of energy efficiency policies and programmes
- Stakeholders quantifying cuts in GHG emissions due to initiatives at project, organizational or regional level

Benefits of the ISO standards

Adopting ISO standards to determine energy savings – whether in projects, organizations or regions – can help to manage increased numbers of national, regional and private methodologies. ISO/TC 257's International Standards will provide the comprehensive tools to better understand and communicate scores at different levels, and to improve performance.

Because these standards cover both producers and users of energy resources, their beneficiaries will be highly diverse. The new standards will help avoid technical barriers to trade while stimulating the market for energy efficiency services providers, most of which are small- and medium-sized enterprises. The standards will make efficiency measures more reliable and competitive in energy management and public administration. They will also reduce technical barriers in energy savings trade and, hopefully, ignite a flourishing market.

When used properly, the standards can bring users significant advantages and benefits. These include:

- More opportunities to identify worthwhile investment in technologies/projects
- Enhanced clarity in understanding energy savings in projects/organizations/regions
- Greater confidence in the guaranteed/declared energy savings for projects
- Increased potential to use energy rationally and to minimize waste
- More consistent, scientific and effective policy instruments to promote efficiency or cut consumption

- Greater assurance for consumers of the validity of energy savings
- More firmly grounded assessments of GHG emission reductions linked to projects, organizations and programmes
- No technical barriers for energy efficiency services

These advantages and benefits contribute directly and indirectly to the interested parties' commitments to improved energy performance and sustainable development.

Key factors for success

A validation process by independent parties is the key factor in driving global acceptance of the ISO standards (such as certification of ISO 9000 series or ISO 14000 series standards). Similarly, the validation process is also an essential component of the GHG emissions reduction mechanism (liking Clean Development Mechanism, CDM). These standards also need a validation process that can be implemented by an independent party who will evaluate or verify the energy savings from projects, organization or regions. This will improve stakeholders' confidence in energy savings resulting from energy efficiency improvements. To establish a solid and practical validation process of energy savings according with these international standards, it is necessary to develop an integrated framework defining procedures for validating, requirements of validation bodies and competence of evaluator.

The new standards, combined with a validation progress, will give policy-makers greater confidence in making decisions based on potential energy savings from policy instrument liking energy efficiency programs. Furthermore, also as an important policy instrument, the energy savings trading systems (liking White Certification Scheme in Europe) built by authorities also show its big demand on standardization of procedures, methodologies, principles, requirements and guidelines for measurement and verification of energy savings in projects and organizations. The effective policy instrument will also push the governors, enterprise administrators or managers of energy efficiency projects to consider the energy savings results according to the international standards.

Capacity building is another key factor in the smooth implementation of standards. To help move the basic methods in the standards into real applications, it is necessary to have an abundance of competent personnel to apply these standards. It is important to develop a training and education program for the evaluators or verifiers of energy savings who will use the international standards. Efficiency Valuation Organization (EVO) has carried out a Certified Measurement & Verification Professionals (CMVP) program for persons determining energy savings of projects globally. It may provide best practices for future capacity building program for these international standards.

Conclusions

The effective measurement, calculation and verification of energy savings are the cornerstone of energy efficiency and sustainable development. In order to be successful, they require standardized tools, technologies and policies. Ongoing concerns about increasing energy demand and climate change have significantly affected global practices in recent years and both suppliers and users of energy resources have now to save energy and to improve energy efficiency. The work products of ISO/TC 257 – the basic standards for determination of energy savings in projects, organizations and regions and others – provide effective tools, including quantitative methodologies, for different stakeholders to better define, adopt, manage and improve the technical and management measures to achieve energy savings and increase energy efficiency. When used properly, these tools can provide significant advantages and benefits to users in both the private and public sectors. As a solid technical foundation for energy savings quantification, the ISO standards of energy savings may ignite a flourishing market of energy savings trade. Key factors include validation process, policy instrument and personnel competence will impact the wide use of these ISO standards.

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Sustainability – Measuring Environmental Impacts

Sriram Gopal, Kevin Messner, Wayne Morris

Association of Home Appliance Manufacturers

Abstract

The term “Sustainability” is well on its way to being incorporated into the standard business lexicon as manufactured products are evaluated and designed to lessen their environmental impact. Defining and measuring sustainability has been more difficult. The appliance industry has taken the next steps to integrate sustainable practices throughout its value chain. Historically in the appliance industry, the environmental burden of products was measured through energy efficiency or water efficiency, in addition to non-environmental measures such as safety and performance. Now, multi-attribute measures have been implemented, so the industry must also look at the material composition and end-of-life disposition of products/packaging, as well as the overall operations of the facilities that manufacture these appliances and their supply chains. In 2010, the Association of Home Appliance Manufacturers (AHAM) embarked on a process to develop a series of technical sustainability standards. Their goal is to comprehensively measure, and then reduce, the overall environmental impact of home appliances. Another important goal is to establish one credible standard that avoids competing and confusing standards that may or may not be relevant or accurate. AHAM’s standard covering refrigeration products was published in June 2012, and 2013 will see the release of standards covering, clothes washers, dishwashers and clothes dryers. This paper describes the process AHAM is using to develop these standards, which starts with Life Cycle Assessment and includes pilot testing and collaborative input from key stakeholders in government, retail, academia, environmental advocacy, and others with expertise in sustainability.

Introduction

The Association of Home Appliance Manufacturers (AHAM) is a trade association that represents manufacturers of major, portable and floor care home appliances, and suppliers to the industry. AHAM’s membership includes over 150 companies located throughout the world. In the U.S., AHAM members employ tens of thousands of people and produce more than 95% of the household appliances shipped for sale. The factory shipment value of these products is more than $30 billion annually. The home appliance industry, through its products and innovation, is essential to U.S. consumer lifestyle, health, safety and convenience. Through its technology, employees and productivity, the industry contributes significantly to U.S. jobs and economic security. Home appliances also are a success story in terms of energy efficiency and environmental protection. New appliances often represent the most effective choice a consumer can make to reduce home energy use and costs.

AHAM is also a standards development organization, accredited by the American National Standards Institute (ANSI). The Association authors numerous appliance performance testing standards used by manufacturers, consumer organizations and governmental bodies to rate and compare appliances. AHAM’s consumer safety education program has educated millions of consumers on ways to properly and safely use appliances such as portable heaters, clothes dryers, and cooking products.

What Do We Mean By “Sustainability?”

There are many definitions of Sustainability or Sustainable Development. One definition was discussed when the World Commission on Environment and Development was convened in 1983 by the United

Nations. The commission was created to address growing concern "about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development." In establishing the commission, the UN General Assembly recognized that environmental problems were global in nature and determined that it was in the common interest of all nations to establish policies for sustainable development.

The Commission (also known as the Brundtland Commission in tribute to its Chair, Gro Harlem Brundtland) defined Sustainable Development in 1987 as a way of "development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs." It contains within it two key concepts:

1. the concept of 'needs,' in particular the essential needs of the world's poor, to which overriding priority should be given; and
2. the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

In the U.S., the Environmental Protection Agency (EPA) has also embraced the concept of sustainability, stating that "[a] public policy perspective would define sustainability as the satisfaction of basic economic, social and security needs now and in the future without undermining the natural resource base and environmental quality on which life depends." This public policy recognizes "the need to support a growing economy while reducing the social and economic costs of economic growth."

The appliance sector has been advancing with technology continuously since it first appeared in the early 20th century. Today, technological advancements are occurring at an ever more rapid pace along with the size of many of the appliances. The main driver in the last 40 years has been to reduce the overall energy demands of the products and the achievements in this direction have been dramatic.

When the first life cycle analysis studies were performed on appliances in the latter 1990's, it clearly showed that energy during the use phase was the dominant driver on the environment. Today, while this is still a major contributor, it may not be the only major driver, and we need to be acutely aware of what those drivers may be. Through more advanced life cycle analysis approaches, we can better quantify the demands of these products on the environment.

Why Are We Measuring Sustainability?

Certainly we could be satisfied with just measuring the energy when the product is used, but as we continue to make improvements in this area, we need to be able to apply a life cycle study approach to the inter-relationship between energy and other environmental demand factors.

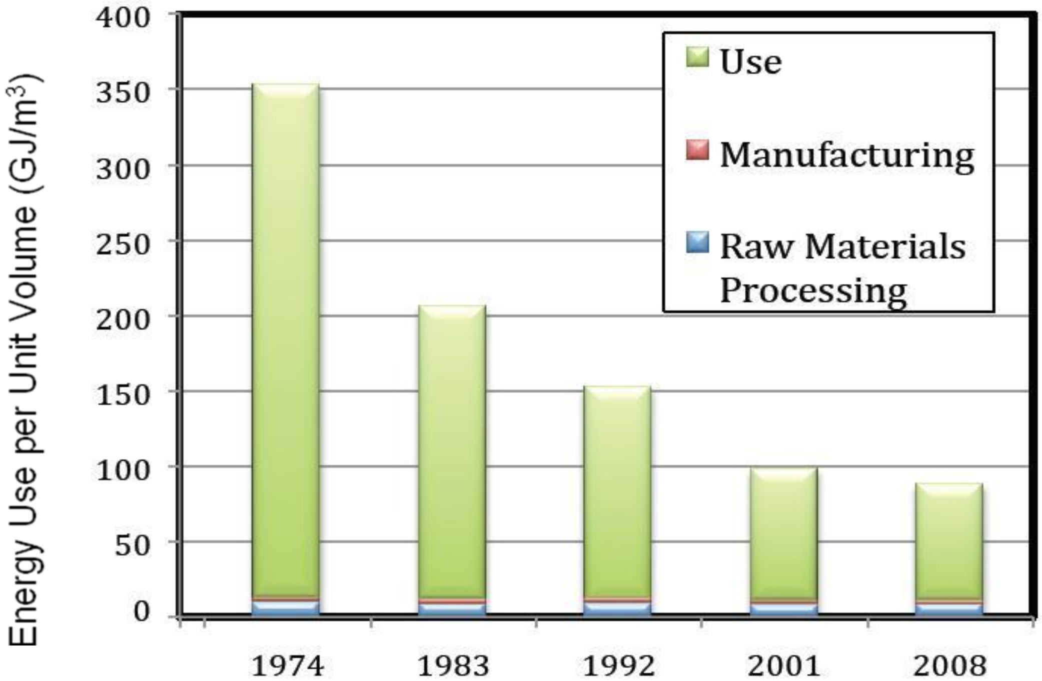

Figure 1: Appliance Remanufacturing and Energy Savings (Source: Boustani et al. (2010))

As home appliances become more energy efficient, relatively speaking, the proportion of energy impacts from other activities within the product life cycle are increasing (see Figure 1). While this shows energy being significant, when we measure the full life cycle of the product, energy is but one of several attributes we need to consider.

One key element beyond energy will be the design of products in such a way as to minimize their environmental impacts through the materials that are used and how they are handled at end-of-life. An integrated way to quantify the environmental impact of products and to assess different product elements will assist design engineers with a methodology and tool with which to judge different designs and look for ways to reduce the overall demand on the environment.

Many companies are already assessing the impact of their products on the environment. They focus on this in their advertising and consumers are becoming more aware of the impact of their purchasing decisions on the environment. Increasingly, retailers are beginning to be aware that their purchasing decisions of what products they carry within their portfolio can have a definite impact on the overall environment.

We currently see more than 350 marks, symbols or “ecologos” across a variety of product sectors (see Figure 2). Many of these represent certification programs. Some represent single-attribute programs and others look at more than one attribute. Certainly consumers could easily be confused with all these environmental marks if care is not taken to create programs based on sound principles of science. These programs must also be transparent and equitable.

Figure 2: Ecologos (Source: CSA Standards)

Standards

AHAM believes the development of open and transparent standards using expertise from standards development organizations, industry experts and consultation with sustainability experts will benefit its member companies. To this end, we have involved multiple organizations, including The Sustainability Consortium, several individual retailers, U.S. Environmental Protection Agency, Environment Canada and Consumers Union. We are meeting regularly with these groups to discuss the process and the standards throughout their development. We believe a set of measurement standards will allow companies to judge their own products against those of other companies, and within their own product portfolio, in order to make decisions about future designs. Consensus standards development will allow all parties to present technical information and to participate among their peers.

The AHAM standards development process is also committed to ensuring that the development of the standard follows the principles outlined in ISO 14020 on Environmental Labels and Declarations. These core principles, as applied to the sustainability standard for refrigeration appliances, are listed below:

1. The product sustainability standard shall be accurate, verifiable, relevant and not misleading.
2. Procedures and requirements for the product sustainability standard shall not create unnecessary obstacles to international trade.
3. The product sustainability standard shall be based on scientific methodology that is sufficiently thorough and comprehensive to support the claim and that produces results that are accurate and reproducible.

4. Information concerning the procedure, methodology, and any criteria used to support the product sustainability standard shall be available and provided upon request to all interested parties.
5. The development of the product sustainability standard shall take into consideration all relevant aspects of the life cycle of the product.
6. The product sustainability standard shall not inhibit innovation.
7. All organizations, regardless of size, should have equal opportunity to use the product sustainability standard.
8. The process of developing the product sustainability standard should include an open, participatory consultation with interested parties.
9. Information on the environmental aspects of products and services relevant to the product sustainability standard shall be available to purchasers and potential purchasers.
10. The focus of the product sustainability standard shall be on improving the sustainability performance of products designed today and in the future, rather than those designed in the past. We support the environmentally responsible disposal and recycling of appliances currently at end-of-life through existing initiatives such as the Appliance Recycling Information Center (ARIC) and North American Appliance Resource Management Alliance (NAARMA).
11. The product sustainability standard should lead to the differentiation of environmentally preferable products.
12. The requirements for the product sustainability standard should evolve with changes in the marketplace.
13. The requirements for the product sustainability standard should not set pricing or other commercial terms.

In addition, the standards are being drafted as to ensure conformity with the U.S. Federal Trade Commission's *Guides for the Use of Environmental Marketing Claims*, often simply called the FTC Green Guides.

Tools

The initial stages of the standard development process is built on an extensive review of the available life cycle literature for a given product category. While a number of life cycle analyses have been conducted, many focused on appliances distinctly different from those produced today, or in North America. In some cases, they also do not cover important environmental attributes. Therefore, in this standard development process, AHAM, CSA Standards Group, and UL Environment (ULE) partnered to produce more comprehensive life cycle analysis and "hot spot" analysis of many of these products for today's product designs. These life cycle analyses and hot-spot analysis will guide the development of the selection of the major attributes and help us derive the relative weighting of these attributes. Figure 3 is an example of the life cycle screening.

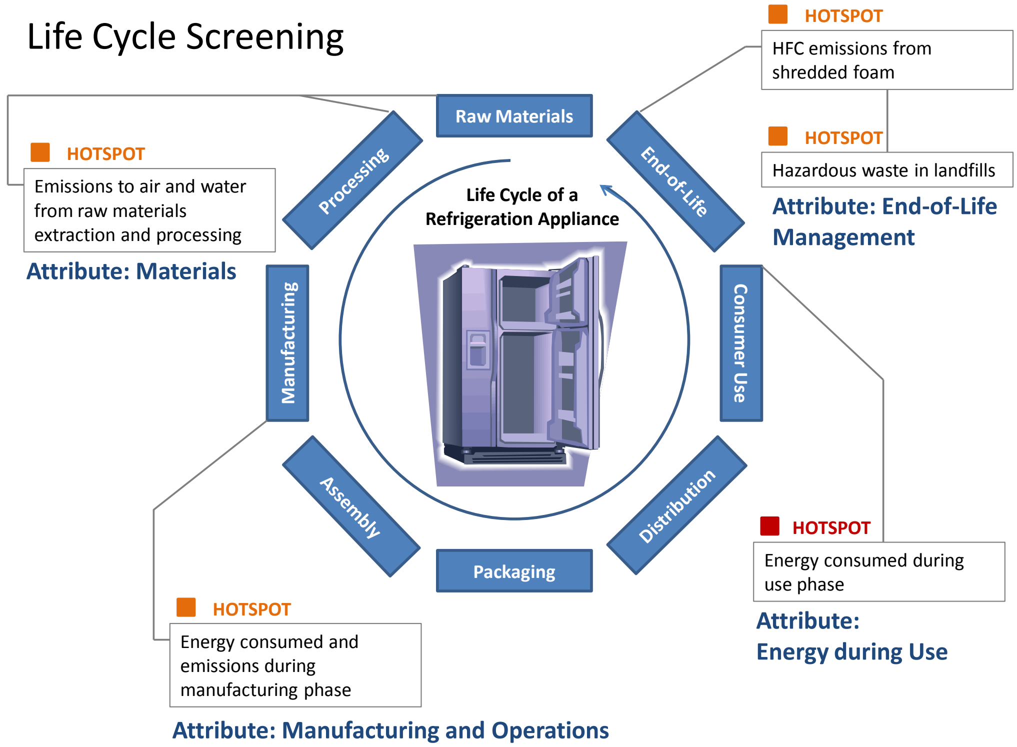

Figure 3: Life Cycle Screening

In all of the appliance categories AHAM has studied, there are several key attributes with impact on the overall environmental position of these appliances. These may include:

- Materials
- Energy During Use
- Manufacturing and Operations
- Performance
- End-of-Life Management
- Innovation

Nomenclature

We are utilizing the nomenclature of environmental effects as found in the ISO 14000 series of standards as in Figure 4.

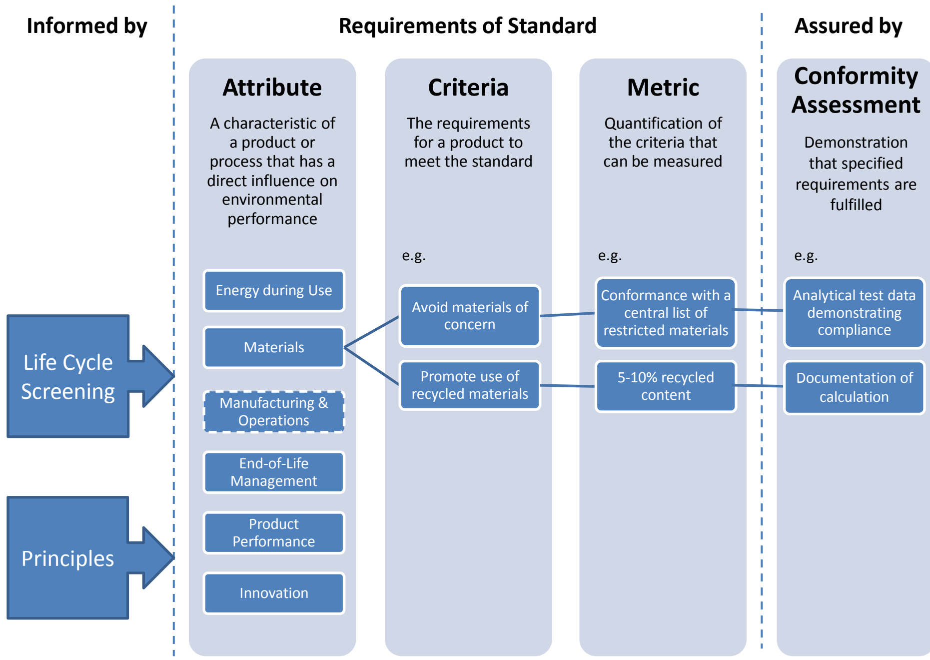

Figure 4: Standards Requirements

Development

The eventual goal for these standards is to develop consensus standards within the framework first of the American National Standards Institute (ANSI) and Standards Council of Canada (SCC) framework for North American standards. AHAM has joined together with three organizations to assist with these standards developments: CSA Standards, Underwriters Laboratories, and P.E./Five Winds International.

CSA Standards is a leading standards-based solutions organization serving industry, government, consumers and other interested parties in North America and the global marketplace. Focusing on standards and codes development, application products, training, advisory and personnel certification services, the organization aims to enhance public safety, improve quality of life, preserve the environment and facilitate trade. For more information, visit www.csa.ca.

The environmental group at Underwriters Laboratories (UL) supports the growth and development of sustainable products and services in the global marketplace through standards development and independent third-party assessment and certification. It is a wholly owned subsidiary of Underwriters Laboratories, a global leader in conformity assessment that has been testing products and writing standards for more than a century. UL currently offers Environmental Claims Validation (ECV), a service testing and verifying manufacturers' self-declared environmental claims, Sustainable Products Certification (SPC), a service testing and certifying products to accepted industry standards for environmental sustainability and Energy Efficiency Certification (EEC), a service testing and verifying product compliance with mandatory and voluntary energy efficiency regulations and programs. UL is developing additional environmental standards, as well as training and advisory services to support organizations in the sustainable products and services industry. For more information, visit www.ulenvironment.com.

Five Winds International, which recently merged with P.E. International, is an internationally recognized sustainability consulting firm, has been selected as a project manager for the AHAM project. Five Winds brings twelve years experience in improving the sustainability of companies and has been instrumental in helping to write international environmental standards.

These sustainability standards are being developed with a variety of uses in mind, and there is strong commitment from both member companies and retailers to employ the standards. Companies may simply use them for self-assessment in order to determine those areas in which they should concentrate their resources. They may also seek third-party certification using the standard to make a claim of sustainability on their products.

AHAM has made considerable progress in the three years since it first embarked upon this project. Hundreds of meetings, both virtual and face-to-face, took place between company representatives that were divided into Task Forces based on product category. AHAM facilitated these discussions, but it was AHAM members that took the lead in drafting the standards. ULE provided support in the LCA screening while CSA has taken the lead in the editorial process.

The sustainability standard for refrigeration products was published in 2012 and is currently in the ANSI accreditation process. Standards for clothes washers are nearing completion for release in 2013. The development process is also well underway for non-microwave kitchen cooking appliances, dishwashers, and clothes dryers with tentative publication dates in late 2013/early 2014. Sustainability standards on smaller appliances such as microwave ovens, room air conditioners and dehumidifiers will follow in 2014. At that point, it will also be time to re-visit the earlier standards in order to update them based on experience and changes in the regulatory environment.

Accreditation and Conformity Assessment

AHAM's standard development process is a hybrid, wherein most of the drafting is done by industry experts with input from AHAM, CSA, UL and Five Winds. Key Outside stakeholders are consulted regularly and are invited to comment on drafts of the standard. This approach aims to find a balance between transparency and expediency. However, once the AHAM-UL-CSA process is completed and the ANSI accreditation process begins, the amount of outside input also increases, thereby lengthening the timeline. On the other hand, it would be difficult to go straight to the accreditation process without first having a standard that companies can use to gain practical knowledge that will inform the ANSI process.

From the very outset, conformity assessment has not been included in the standards because they are designed to be strictly voluntary. Companies may use the standards simply to determine where to best allocate resources. However, should a company wish to certify a product using the standard, it is free to self-certify. The standards were never designed to make any certification, self or 3rd party, a requirement; however, they do contain provisions requiring a product to achieve a certain level of performance under the standard before allowing a company to make a claim of sustainability.

Lessons Learned

Now that AHAM has spent over three years in the sustainability arena, there have been a number of teaching moments that are applicable to not only future appliance standards, but to any other industry wishing to establish similar standards.

Consensus building is essential

AHAM's sustainability standards were developed through a collaborative effort with key stakeholders through a consensus process. Key steps in the process include identifying and recruiting committed individuals with the proper knowledge and skills to participate. Defining the goals of the effort is also important, as this establishes the boundaries of discussion. Recognizing that the companies involved are competitors in the marketplace, the process should encourage frank and substantive dialogue in which parties are given a number of options from which they can choose an appropriate compromise. However, compromise should never sacrifice the over-arching goal of these sustainability standards, which is to reduce the environmental impacts that result from the manufacture, use and disposal of home appliances.

Scoping is key

There are several aspects to scoping with respect to AHAM's sustainability standards. First, there is the scope of product categories that a standard will cover. The drafters of the standard must also determine the key attributes that the standard will address. The discussions covering the standard's scope should take place early on in the development process and must be well-documented. That said, there will be instances where circumstances will require that the scoping be modified, but those modifications should be well-considered.

Pay attention to the regulatory environment

The home appliance industry is heavily regulated and those regulations are constantly shifting. The standard development process has had to take new regulations into account. For example, the publication of the FTC Green Guides in October 2012 resulted in substantial changes to the standards that were being drafted at the time.

Conclusion

Through the combined efforts of our industry and other stakeholders, we believe that the AHAM-CSA-ULE sustainability standards will offer the appliance industry and others in this industry segment a set of objective standards for measuring product sustainability for future designs and for improvements to the environment. The appliance industry is pleased to continue our leadership in the area of environmental responsibility, and we look forward to the technical expertise provided by many stakeholders to produce strong, technical product sustainability standards that can help in the design of the next generation of appliances.

Economic analysis of the energy-efficient household appliances and the rebound effect

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Abstract

Energy efficiency improvement is one of the means to reduce energy consumption and carbon emissions. However, potential energy savings and carbon reductions resulting from technological improvements in energy consumption may be reduced by a rebound effect.

The rebound effect refers to the idea that some or all of the expected reductions in energy consumption, as a result of energy efficiency improvements, are offset by an increasing demand for energy services, arising from decrease of the effective price of energy services resulting from those improvements.

The present paper explores the rebound effects from an economist's viewpoint by applying a general equilibrium model in three sectors to measure these effects on the household side. Both, direct and indirect rebound effects expressed as efficiency elasticity and price elasticity are quantified and commented.

On the basis of our theoretical discussion and numerical simulation, we show that he size of direct and indirect rebound effects strongly depends on the elasticity of substitution between energy services.

1. Introduction

Energy efficiency improvement is one of the means to reduce energy consumption and carbon emissions. However, potential energy savings and carbon reductions resulting from technological improvements in energy consumption may be reduced by a rebound effect (Wigley, 1997).
The rebound effect appears when some or all of the expected reductions in energy consumption, as a result of energy-efficiency improvements, are offset by an increasing demand for energy services, arising from decrease of the effective price of energy services resulting from those improvements (Greening et al. 2000).

The first academic discussion of the rebound effect goes back to Jevons (1865) who observed that improvements in the efficiency of steam engines would lead to increasing rather than decreasing coal consumption. More recently, Khazzoom (1980) argued that improved efficiency reduces the effective price of energy and hence results in increasing demand. Following this pioneering study, a considerable work has been done on the rebound effect; these studies focused on theoretical and empirical aspects and are extremely diverse in terms of definitions, methodological approaches and data sources (Lovins, 1988; Henly et al., 1988; Brookes, 1990, 2000; Greene, 1992; Saunders, 1992, 2000; Herring, 1999, 2006; Berkhout et al., 2000; Reinhard et al., 2000; Roy, 2000; Birol et al., 2000; Jaccard et al., 2000; Sanne, 2000; Binswanger, 2001; Bentzen, 2004; Grepperud et al., 2004; Dimitropoulos, 2007; Sorrell et al., 2007; Brannlund et al., 2007; Sorrell, 2009; Sorrell et al., 2009; Jonas et al., 2009; Taoyuan, 2010; Jeroen, 2011).

Rebound effects may derive from energy efficiency improvements in production sectors and consumption household behavior. The literature distinguishes three types of rebound effect: direct, indirect and economy-wide (Greening et al. 2000).

- Direct rebound effect: increased energy efficiency for a particular energy service lowers the price of that service, and hence increases the consumption of it because of the substitution effect and the income effect.
- Indirect effects: the lower effective price of the energy service may lead to increased consumption of other goods, services and factors of production that also require energy.

- Economy-wide effects: a price reduction of the energy service may reduce the price of intermediate and final goods throughout the economy, leading to series of price and quantity adjustments in supply and demand in all sectors. An improvement in energy efficiency has an effect of reducing energy prices and leads to faster economic growth which eventually leads to an increase in energy demand (Barker et al. 2009). According to Sorrell (2009), the overall or economy-wide effects are the addition of direct and indirect effects.

This study is confined to direct and indirect rebound effects in household behavior.
Section 2 presents the general equilibrium model for three sectors in the economy (Energy and two types of appliance) where we:

- Model the behavior of households, energy suppliers and appliances suppliers.
- Determine and comment on the direct and indirect rebound effects expressed as efficiency elasticity and prices elasticity.
- Determine equilibrium prices and quantities which quantify the direct and indirect rebound effects.
- Give a numerical example to illustrate the results of the model.

Section 3 concludes the paper.

2. The rebound effect model

2.1. Consumer's behavior

Energy consumption in itself does not provide utility, but rather the services of the equipment that operate on energy. The consumer can thus be regarded as a producer of useful services, using energy as an input (Berkhout et al. 2000). For example, energy services represent the heating of a dwelling at a certain temperature, a certain number of kilometres travelled at a certain speed, comfort and reliability, etc. These services are assured by the consumption of energy goods such as air conditioners, cars, refrigerators, TV, etc (Quirion, 2005).

We consider two types of energy services, G and Q. Both have a price, respectively P_G and P_Q. The consumer maximizes the utility function $U(G,Q)$, under his budget constraint. In this model, a Constant Elasticity of Substitution (CES) utility function is used. The household maximization program is given by:

$$\max_{(G,Q)} U(G,Q) = [\theta G^{-\rho} + (1-\theta)Q^{-\rho}]^{-\frac{1}{\rho}} \quad (1)$$

$$s.t$$

$$P_G G + P_Q Q \leq R \quad (2)$$

Where ρ denotes the substitution parameter; the elasticity of substitution σ then equals $\frac{1}{1+\rho}$.

The energy service G (resp Q) is produced by the consumer, by combining equipment g (resp q) and energy E_g (resp E_q) in a Cobb-Douglas production function. Formally:

$$G = E_g^{\alpha} g^{1-\alpha} \quad (3)$$

$$Q = E_q^{\beta} q^{1-\beta} \quad (4)$$

where $\alpha, \beta \in (0,1)$.

Consumer purchases energy, appliance g and appliance q at the respective prices P_E, P_g and P_q. These goods cannot be consumed infinitely, since the consumer has a limited revenue R.

D_G denotes the energy service cost for appliance g.

$$D_G = P_G G \quad (5)$$

$$= P_E E_g + P_g g \quad (6)$$

Also, D_Q denotes the energy service cost for appliance q.

$$D_Q = P_Q Q \tag{7}$$

$$= P_E E_q + P_q q \tag{8}$$

Then, the budget constraint faced by the consumer may be rewritten as follows:

$$P_E E_g + P_g g + P_E E_q + P_q q \leq R \tag{9}$$

The household maximization program described above may be changed as follows:

$$\max_{(E_g, E_q, g, q)} U(G, Q) = [\theta(E_g^\alpha g^{1-\alpha})^{-\rho} + (1-\theta)(E_q^\beta q^{1-\beta})^{-\rho}]^{-\frac{1}{\rho}} \tag{10}$$

$$s.t$$

$$P_E E_g + P_g g + P_E E_q + P_q q \leq R$$

First-order conditions lead to energy and goods demands:

$$E_g = \left(\frac{R}{P_E}\right)\left(\frac{\alpha\beta A}{\alpha + \beta A}\right) \tag{11}$$

$$E_q = \left(\frac{R}{P_E}\right)\left(\frac{\alpha\beta}{\alpha + \beta A}\right) \tag{12}$$

$$g = \left(\frac{R}{P_g}\right)\left(\frac{(1-\alpha)\beta A}{\alpha + \beta A}\right) \tag{13}$$

$$q = \left(\frac{R}{P_q}\right)\left(\frac{(1-\beta)\alpha}{\alpha + \beta A}\right) \tag{14}$$

Where A is given by this expression:

$$A = \left[\frac{\alpha\theta}{\beta(1-\theta)}\right]^{\frac{1}{1+\rho}} \left[\frac{\left(\frac{1-\beta}{\beta}\frac{P_E}{P_q}\right)^{1-\beta}}{\left(\frac{1-\alpha}{\alpha}\frac{P_E}{P_g}\right)^{1-\alpha}}\right]^{\frac{\rho}{1+\rho}} \tag{15}$$

The total energy demand is:

$$E_d = (E_g + E_q)_d = \frac{R}{P_E}\left(\frac{\alpha\beta(A+1)}{\alpha + \beta A}\right) \tag{16}$$

Based on these demand functions, the two energy services can be calculated:

$$G = \left(\frac{R\alpha\beta A}{\alpha + \beta A}\right)\left(\frac{1}{P_E}\right)^\alpha \left(\frac{1}{P_g}\right)^{1-\alpha}\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha} \tag{17}$$

$$Q = \left(\frac{R\alpha\beta}{\alpha + \beta A}\right)\left(\frac{1}{P_E}\right)^\beta \left(\frac{1}{P_q}\right)^{1-\beta}\left(\frac{1-\beta}{\beta}\right)^{1-\beta} \tag{18}$$

The energy service cost D_G may be rewritten as follows:

$$D_G = \frac{R\beta A}{\alpha + \beta A} \tag{19}$$

Based on (17), we then know

$$D_G = \left(\frac{P_E}{\alpha}\right)^\alpha \left(\frac{P_g}{1-\alpha}\right)^{1-\alpha} G = P_G G \tag{20}$$

In a similar way, the energy service cost D_Q may be rewritten as follows:

$$D_Q = \frac{R\alpha}{\alpha + \beta A} \tag{21}$$

With (18), we get:

$$D_Q = \left(\frac{P_E}{\beta}\right)^{\beta}\left(\frac{P_q}{1-\beta}\right)^{1-\beta} Q = P_Q Q \qquad (22)$$

where P_G and P_Q represent the consumer price-index for the energy services which are given by the standard form for a Cobb-Douglas function:

$$P_G = \left(\frac{P_E}{\alpha}\right)^{\alpha}\left(\frac{P_g}{1-\alpha}\right)^{1-\alpha} \qquad (23)$$

$$P_Q = \left(\frac{P_E}{\beta}\right)^{\beta}\left(\frac{P_q}{1-\beta}\right)^{1-\beta} \qquad (24)$$

Energy efficiency coefficient defined as the ratio between the useful energy outputs and the energy inputs is given for each appliance g and q:

$$e_g = \frac{G}{E_g} = \left(\frac{P_E}{P_g}\right)^{1-\alpha}\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha} \qquad (25)$$

$$e_q = \frac{Q}{E_q} = \left(\frac{P_E}{P_q}\right)^{1-\beta}\left(\frac{1-\beta}{\beta}\right)^{1-\beta} \qquad (26)$$

Now substitute the energy efficiency coefficients from equation (25) and (26) into the expression (15) to obtain:

$$A = \left[\frac{\alpha\theta}{\beta(1-\theta)}\right]^{\frac{1}{1+\rho}}\left[\frac{e_q}{e_g}\right]^{\frac{\rho}{1+\rho}} \qquad (27)$$

Also, the energy service demands may be rewritten as a function of the energy efficiency coefficients:

$$G = \left(\frac{R}{P_E}\,\frac{\alpha\beta A}{\alpha+\beta A}\right) e_g \qquad (28)$$

$$Q = \left(\frac{R}{P_E}\,\frac{\alpha\beta}{\alpha+\beta A}\right) e_q \qquad (29)$$

Combining (23) and (25), the energy service price P_G may be rewritten as:

$$P_G = \frac{P_E}{\alpha e_g} \qquad (30)$$

Also, combining (24) and (26), the energy service price P_Q may be rewritten as:

$$P_Q = \frac{P_E}{\beta e_q} \qquad (31)$$

To analyze the impact of energy efficiency improvements on the households energy consumption, we suppose that G represents the energy services of the equipment which becomes more efficient. Thus, we assume that e_g increases and e_q remains constant. Then, we study its impact on the household energy demand.

The change in energy demand following a small change in energy efficiency may be measured by the efficiency elasticity of the energy demand:

$$\nu_{E_g}^{e_g} = -\left(\frac{\rho}{1+\rho}\right)\left(\frac{\alpha}{\alpha+\beta A}\right) \qquad (32)$$

$$\nu_{E_q}^{e_g} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A}{\alpha+\beta A}\right) \qquad (33)$$

2.1.1. The measure of the direct rebound effect

a) The rebound effect as efficiency elasticity

In order to measure the direct rebound effect, we have to determine the efficiency elasticity of the demand for energy service G:

$$\nu_G^{e_g} = \left(\frac{1}{1+\rho}\right)\left(1 + \frac{A\beta\rho}{\alpha + \beta A}\right) \qquad (34)$$

Then, it can easily be shown that:

$$\nu_{E_g}^{e_g} = \nu_G^{e_g} - 1 \qquad (35)$$

We find analytically the expression used by Khazzoom, 1980; Greene et al.1999a; Berkhout et al., 2000; Binswanger, 2001; Sorrell et al., 2009; and Dimitropoulos, 2007a; to measure the direct rebound effect. Hence, the efficiency elasticity of energy demand $\nu_{E_g}^{e_g}$ is equal to the efficiency elasticity of the demand for energy service $\nu_G^{e_g}$ minus one.
Rebound due to energy efficiency improvements may be understood in terms of technical-engineering versus behavioral-economic phenomena. In fact, engineering models predict that an $x\%$ improvement in energy efficiency should lead to an $x\%$ reduction in energy consumption (i.e. $\nu_{E_g}^{e_g} = -1$). So, the engineering approach does not correctly quantify the impact of conservation measures on the demand for energy when it consider that $\nu_G^{e_g} = 0$.

Besides the engineering side, there is also an economic side which considers that a positive efficiency elasticity of the demand for energy service ($\nu_G^{e_g} \geq 0$) may be taken as a direct measure of the rebound effect (Berkhout et al. 2000). For example, if $\nu_G^{e_g} = 10\%$, then $\nu_{E_g}^{e_g} = 90\%$and the rebound effect is equal to 10% . This means that 10% of the potential energy savings are taken back as a result of the increased demand for energy services.

b) The rebound effect as price elasticity

In the following paragraph, we show that the rebound effect may be equal to one of two price elasticities, namely:
$\nu_G^{P_G}$: the elasticity of demand for energy services with respect to the energy cost of energy services(PG),
$\nu_E^{P_E}$: the elasticity of energy demand with respect to the price of energy.

First, the definition of the direct rebound effect may be based on the elasticity of the demand for a particular energy service, with respect to the energy cost of energy services. In fact, based on (35) we know:

$$\nu_{E_g}^{e_g} = \frac{\partial G}{\partial e_g}\frac{e_g}{G} - 1 \qquad (36)$$

$$= \frac{\partial G}{\partial P_G}\frac{\partial P_G}{\partial e_g}\frac{e_g}{P_G}\frac{P_G}{G} - 1 \qquad (37)$$

In this equation (40),$-\nu_G^{P_G}$ measures rebound in terms of energy cost elasticity where minus energy service price elasticity of useful service is used as a proxy for the efficiency elasticity of useful service $\nu_G^{e_g}$.

Secondly, the rebound may be captured by $\nu_{E_g}^{P_E}$ because $\nu_G^{P_G} = \nu_{E_g}^{P_E}$:

$$\nu_G^{P_G} = \frac{\partial G}{\partial P_G}\frac{P_G}{G} \qquad (41)$$

Or we have:

$$\begin{cases} G = e_g E_g \\ P_G = \frac{P_E}{\alpha e_g}. \end{cases} \Leftrightarrow \frac{P_G}{G} = \frac{1}{\alpha e_g^2}$$

Also:

$$\frac{\partial G}{\partial P_G} = \frac{\partial G}{\partial E_g}\frac{\partial E_g}{\partial P_G} \tag{42}$$
$$= \frac{\partial G}{\partial E_g}\frac{\partial E_g}{\partial P_E}\frac{\partial P_E}{\partial P_G}$$
$$= \alpha e_g^2 \frac{\partial P_E}{\partial P_G}$$

Now substitute into (41) to obtain:

$$\nu_G^{P_G} = \nu_{E_g}^{P_E}$$

So that,

$$\nu_{E_g}^{e_g} = -\nu_{E_g}^{P_E} - 1 \tag{43}$$

This expression shows that the rebound effect may be calculated by the price elasticity of energy demand for the relevant energy service.

c) Interpretation

Under this model, we showed and verified that the direct rebound effect (noted RE_{direct}) is given by:

$$RE_{direct} = \nu_G^{e_g} = -\nu_G^{P_G} = -\nu_{E_g}^{P_E} \tag{44}$$

This means that nearly $RE_{direct}\%$ of the engineer's estimate of the energy savings is lost because of the feedback from the engineering measures to the economy. In fact, consumers will react to changes in the energy efficiency of appliance (e_g). It is verified that the increase in energy efficiency appliances has an impact on the decrease in both energy service price and energy service cost which lead consumers to save an amount of money:

$$\nu_{P_G}^{e_g} = -1 \tag{45}$$

$$\nu_{D_G}^{e_g} = -\left(\frac{\rho}{1+\rho}\right)\left(\frac{\alpha}{\alpha+\beta A}\right) \tag{46}$$

For consumers, the direct effect of a price reduction may be decomposed into a substitution effect and an income effect.

- The substitution effect: if the price of the energy service P_G drops following an energy efficiency improvement (45), the energy service G becomes less expensive relative to other service Q. This may lead to an increased demand for the service G and therefore the efficiency appliance g.
- The income effect: energy efficiency improvements reduce the cost of energy service G (46) and leads to an amount of money being saved. So, consumers have an additional income which they may choose to spend on the same energy service G and get more of the same appliance g. For example, people may buy more air conditioners when it becomes more efficient, and heat more their homes than before.

2.1.2. The measure of the indirect rebound effect

In this model, the indirect rebound effect is measured by the efficiency elasticity of the demand for energy service Q:

$$\nu_Q^{e_g} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A}{\alpha+\beta A}\right) \tag{47}$$

Recalling the equation (33), we notice that:

$$\nu_{E_q}^{e_g} = \nu_Q^{e_g} \tag{48}$$

Under the engineering side, if the increase in efficiency is implemented, the level of energy demand of appliance q will not be changed $\nu_{E_q}^{e_g} = 0$. However, under our economic analysis we show $\nu_{E_q}^{e_g} \geq 0$. This shows that an improvement of the efficiency of the equipment g may increase the energy consumption of the other equipment q. From this, the indirect rebound effect rises beyond the increase of energy service Q where the energy efficiency e_g is improved.

$$ER_{indirect} = \nu_{E_q}^{e_g} = \nu_Q^{e_g} \tag{49}$$

The prominent mechanism responsible for this type of rebound is believed to be secondary effect, which may also happen by way of income effect. In fact, energy efficiency improvements of appliance g reduce the price of energy service G and have no impact on the price of energy service Q, because:

$$\nu_{P_G}^{e_g} = -1$$

$$\nu_{P_Q}^{e_g} = 0 \tag{50}$$

As a result, an amount of money is saved. This leads to more expenditure on the energy service Q:

$$\nu_{D_Q}^{e_g} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A}{\alpha + \beta A}\right) \tag{51}$$

So, the energy service Q increase, which leads to an increase in energy demand Eq. For example, the use of a more efficient air-conditioner may create more energy demand for lighting, cooking or driving.

2.2. Energy suppliers behavior

We define the energy suppliers production function as a Cobb-Douglas function which takes factor inputs K_E, L_E and converts them to energy output E:

$$E = b\, K_E^{\gamma}\, L_E^{1-\gamma} \tag{52}$$

Given the wage rate w and the capital rate of return r, the cost of the input bundle (K_E, L_E) is:

$$rK_E + wL_E \tag{53}$$

For given r, w and P_E, the suppliers profit-maximization behavior is:

$$\max_{(K_E, L_E)} \Pi_E = P_E b\, K_E^{\gamma}\, L_E^{1-\gamma} - (rK_E + wL_E) \tag{54}$$

First-order conditions are:

$$P_E b \gamma K_E^{\gamma-1} L_E^{1-\gamma} = r \tag{55}$$

$$P_E b(1-\gamma) K_E^{\gamma} L_E^{-\gamma} = w \tag{56}$$

They lead to the marginal rate of transformation:

$$\frac{\gamma}{1-\gamma}\frac{L_E}{K_E} = \frac{r}{w} \tag{57}$$

This can also be written as:

$$K_E = \frac{\gamma}{1-\gamma}\frac{w}{r} L_E \tag{58}$$

Or:

$$L_E = \frac{1-\gamma}{\gamma}\frac{r}{w} K_E \tag{59}$$

Now substitute K_E from equation (58) into (52) and (55) to obtain:

$$E = b\left(\frac{\gamma}{r}\right)^{\gamma}\left(\frac{1-\gamma}{w}\right)^{-\gamma} L_E \quad (60)$$

$$P_E = \frac{1}{b}\left(\frac{r}{\gamma}\right)^{\gamma}\left(\frac{\omega}{1-\gamma}\right)^{1-\gamma} \quad (61)$$

Also, substitute L_E from equation (59) into (52) to obtain:

$$E = b\left(\frac{\gamma}{r}\right)^{1-\gamma}\left(\frac{1-\gamma}{w}\right)^{1-\gamma} K_E \quad (62)$$

Then, based on (60) and (61) we get:

$$P_E E = \frac{\omega}{1-\gamma} L_E \quad (63)$$

and based on (62) and (61) we get:

$$P_E E = \frac{r}{\gamma} K_E \quad (64)$$

2.3. Appliance q producer's behavior

Under perfect competition, the suppliers of appliance q maximize q their profit and production under constant returns to scale. Then a Cobb-Douglas production function is:

$$q = a\, K_q^{\mu}\, L_q^{1-\mu} \quad (65)$$

Given r and w, the firm's cost is:

$$rK_q + wL_q \quad (66)$$

Then the firm's profit maximization problem is:

$$\max_{(K_q, L_q)} \Pi_q = P_q a\, K_q^{\mu}\, L_q^{1-\mu} - (rK_q + wL_q) \quad (67)$$

First-order conditions lead to

$$P_q = \frac{1}{a}\left(\frac{r}{\mu}\right)^{\mu}\left(\frac{\omega}{1-\mu}\right)^{1-\mu} \quad (68)$$

$$P_q q = \frac{1}{a}\frac{\omega}{1-\mu} L_q \quad (69)$$

$$P_q q = \frac{1}{a}\frac{r}{\mu} K_q \quad (70)$$

2.4. Appliance g producer's behavior

Producers of the appliance g have also a Cobb-Douglas production function:

$$g = c\, K_g^{\eta}\, L_g^{1-\eta} \quad (71)$$

and a total cost:

$$rK_g + wL_g \quad (72)$$

For given r, w, and P_g, profit-maximization firm's behavior is:

$$\max_{(K_g, L_g)} \Pi_g = P_g c\, K_g^{\eta}\, L_g^{1-\eta} - (rK_g + wL_g) \quad (73)$$

Based on the first-order conditions we get:

$$P_g = \frac{1}{c}\left(\frac{r}{\eta}\right)^{\eta}\left(\frac{\omega}{1-\eta}\right)^{1-\eta} \quad (74)$$

$$P_g g = \frac{\omega}{1-\eta} L_g \quad (75)$$

$$P_g g = \frac{r}{\eta} K_g \quad (76)$$

2.5. Market equilibrium

This model supposed only three goods: energy E, appliances g and q. Thus, after establishing consumer's and firm's equilibriums, we examine the general equilibrium. In order to simplify the notations, we normalize the number of firms and consumers to one. Market clearing for the three goods implies:

$$E_s = (E_g + E_q)_d \quad (77)$$

$$g_s = g_d \quad (78)$$

$$q_s = q_d \quad (79)$$

Firms are owned by the consumer and this taken into account in the budget constraints. Total income equals then the sum of returns to total capital and labor:

$$R = r(K_E + K_g + K_q) + w(L_E + L_g + L_q) \quad (80)$$

$$= P_E E + P_g g + P_q q$$

If capital supply (noted $\overline{K}$) and labor supply (noted $\overline{L}$) are exogenous, balanced capital and labor markets fulfill:

$$\overline{K} = K_E + K_g + K_q \quad (81)$$

$$\overline{L} = L_E + L_g + L_q \quad (82)$$

Then:

$$R = r\overline{K} + w\overline{L} \quad (83)$$

Now insert (64) and (16) into (77):

$$P_E E_s = P_E E_d \quad (84)$$

$$\frac{rK_E}{\gamma} = \left(\frac{\alpha\beta(A+1)}{\alpha+\beta A}\right) R \quad (85)$$

$$K_E = \left(\frac{\gamma}{r}\right)\left(\frac{\alpha\beta(A+1)}{\alpha+\beta A}\right) R \quad (86)$$

and with (76) and (13) into (78):

$$P_g g_s = P_g g_d \quad (87)$$

$$\frac{rK_g}{\eta} = \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{\alpha\beta A}{\alpha+\beta A}\right) R \quad (88)$$

$$K_g = \left(\frac{\eta}{r}\right)\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{\alpha\beta A}{\alpha+\beta A}\right) R \quad (89)$$

Also, insert (70) and (14) into (79):

$$P_q q_s = P_q q_d \quad (90)$$

$$\frac{rK_q}{\mu} = \left(\frac{1-\beta}{\beta}\right)\left(\frac{\alpha\beta}{\alpha+\beta A}\right) R \quad (91)$$

$$K_q = \left(\frac{\mu}{r}\right)\left(\frac{1-\beta}{\beta}\right)\left(\frac{\alpha\beta}{\alpha+\beta A}\right) R \quad (92)$$

At this step, recall that $\overline{K} = K_E + K_g + K_q$ and substitute (86), (89), and (92) to obtain:

$$\overline{K} = \frac{R}{r}\left(\frac{\alpha\beta}{\alpha+\beta A}\right)\left[\gamma(A+1)+\eta\frac{1-\alpha}{\alpha}A+\mu\frac{1-\beta}{\beta}\right] \qquad (93)$$

Then insert $R = r\overline{K} + w\overline{L}$ into (93):

$$\frac{\alpha\beta}{\alpha+\beta A} = \left(1+w\frac{\overline{L}}{\overline{K}}\right)\left[\gamma(A+1)+\eta\frac{1-\alpha}{\alpha}A+\mu\frac{1-\beta}{\beta}\right] \qquad (94)$$

Equation (94) can also be rearranged as:

$$A\quad\left(\gamma+\eta\frac{1-\alpha}{\alpha}-\frac{1}{\alpha}\right)+\frac{\overline{L}}{\overline{K}}wA\left(\gamma+\eta\frac{1-\alpha}{\alpha}\right)+\frac{\overline{L}}{\overline{K}}w\left(\gamma+\mu\frac{1-\beta}{\beta}\right)$$

$$+\quad\left(\gamma+\mu\frac{1-\beta}{\beta}-\frac{1}{\beta}\right)=0 \qquad (95)$$

By (61), (68), and (74) we can calculate the relative prices. As a result, the expression A mentioned above by (15) can be rewritten as function of labor and capital prices:

$$A=\left(\frac{\theta}{1-\theta}\frac{\alpha}{\beta}\right)^{\frac{1}{1+\rho}}\left[\frac{\left[r^{\gamma-\mu}\omega^{\mu-\gamma}\left(\frac{\mu^{\mu}(1-\mu)^{1-\mu}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}\right)\left(\frac{1-\beta}{\beta}\right)\left(\frac{a}{b}\right)\right]^{1-\beta}}{\left[r^{\gamma-\eta}\omega^{\eta-\gamma}\left(\frac{\eta^{\eta}(1-\eta)^{1-\eta}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}\right)\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{c}{b}\right)\right]^{1-\alpha}}\right]^{\frac{\rho}{1+\rho}} \qquad (96)$$

If the return to capital r is normalized as unity, we obtain:

$$A = Dw^{\varepsilon} \qquad (97)$$

where

$$D=\left(\frac{\theta}{1-\theta}\frac{\alpha}{\beta}\right)^{\frac{1}{1+\rho}}\left[\frac{\left[\left(\frac{\mu^{\mu}(1-\mu)^{1-\mu}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}\right)\left(\frac{1-\beta}{\beta}\right)\left(\frac{a}{b}\right)\right]^{1-\beta}}{\left[\left(\frac{\eta^{\eta}(1-\eta)^{1-\eta}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}\right)\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{c}{b}\right)\right]^{1-\alpha}}\right]^{\frac{\rho}{1+\rho}} \qquad (98)$$

and

$$\varepsilon=\left(\frac{\rho}{1+\rho}\right)\left[\mu(1-\beta)+\gamma(\alpha-\beta)+\eta(\alpha-1)\right] \qquad (99)$$

Applying (97) into (95), we get:

$$D\quad w^{\varepsilon}\left(\gamma+\eta\frac{1-\alpha}{\alpha}-\frac{1}{\alpha}\right)+\frac{\overline{L}}{\overline{K}}Dw^{\varepsilon+1}\left(\gamma+\eta\frac{1-\alpha}{\alpha}\right)+\frac{\overline{L}}{\overline{K}}w\left(\gamma+\mu\frac{1-\beta}{\beta}\right)$$

$$+\quad\left(\gamma+\mu\frac{1-\beta}{\beta}-\frac{1}{\beta}\right)=0 \qquad (100)$$

The equilibrium labor price w is the solution to (100).
This leads to equilibrium prices P_E^*, P_g^*, P_q^*, P_G^* and P_Q^* which are function of w^*, equilibrium quantities E_g^*, E_q^*, g^*, q^* and equilibrium energy services $G^*$and Q^*. Direct and indirect rebound effects are then calculated with P_E^*, P_g^*, P_q^* substituted in (34) and (47).

3. Numerical simulations

Numerically, for $\alpha = \beta = 0.5,\ \theta = 0.5,\ \gamma = \eta = \mu = 0.5,\ \rho = 0.5,\quad a=b=c=1$ equation (100) becomes:

$$2w\frac{\overline{L}}{\overline{K}}-2=0 \qquad (101)$$

Equilibrium prices are:

$$w^* = \left(\frac{\overline{K}}{\overline{L}}\right) \quad (102)$$

$$r^* = 1 \quad (103)$$

$$P_E^* = 2\left(\frac{\overline{K}}{\overline{L}}\right)^{0.5} \quad (104)$$

$$P_g^* = 2\left(\frac{\overline{K}}{\overline{L}}\right)^{0.5} \quad (105)$$

$$P_q^* = 2\left(\frac{\overline{K}}{\overline{L}}\right)^{0.5} \quad (106)$$

Equilibrium quantities of energy and appliances are:

$$g^* = 0.125(\overline{K}\,\overline{L})^{0.5} \quad (107)$$

$$q^* = 0.125(\overline{K}\,\overline{L})^{0.5} \quad (108)$$

$$E_g^* = 0.125(\overline{K}\,\overline{L})^{0.5} \quad (109)$$

$$E_q^* = 0.125(\overline{K}\,\overline{L})^{0.5} \quad (110)$$

Under these circumstances, the increase in the energy efficiency of the appliance g leads to an amount of energy savings generate by the use of this appliance, since

$$\nu_{E_g}^{e_g} = -\left(\frac{\rho}{1+\rho}\right)\left(\frac{\alpha}{\alpha+\beta A}\right) = -0.17 \quad (111)$$

This energy savings is offset by an increase in energy consumption of the appliance q:

$$\nu_{E_q}^{e_g} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A}{\alpha+\beta A}\right) = 0.17 \quad (112)$$

Here, the energy efficiency improvement does not affect energy consumption. This is due to the direct and indirect rebound effects.
First, we have:

$$RE_{direct} = \nu_G^{e_g} = \left(\frac{1}{1+\rho}\right)\left(1+\frac{A\beta\rho}{\alpha+\beta A}\right) = 0.83 \quad (113)$$

This means that 83% of the potential energy savings generated by the use of efficiency appliance g are lost as a result of the increased demand for energy services G. As a consequence, an increase in energy efficiency of the appliance g leads to reduced energy consumption of this appliance at only by 17%.
Secondly, we have:

$$RE_{indirect} = \nu_Q^{e_g} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A}{\alpha+\beta A}\right) = 0.17 \quad (114)$$

So an increase in energy efficiency of the appliance g leads to a rise in energy consumption of appliance q by 17%.

In addition we may calculate the total rebound effect as the sum of the direct and indirect rebound effect.

$$RE_{total} = RE_{direct} + RE_{indirect} \quad (115)$$

$$= 0.83 + 0.17 = 1$$

On the basis of our theoretical discussion, the magnitude of the direct and indirect rebound effects strongly depends on the elasticity of substitution σ (see Fig. 1). In order to assess the sensitivity of the rebound effect to the substitution elasticity, we vary the value of σ, keeping unchanged all other parameters.

- When the elasticity of substitution is assumed to equal zero ($\sigma = 0$) and ($\rho \longrightarrow \infty$), the CES function reduces to a Leontief utility function assuming strict complementarity between the energy services G and Q. In this case, total rebound effect is shared in two equal parts: 50% for direct rebound and 50% for indirect rebound.

- The next simulation is calculated with $0 < \sigma < 1$ and $\rho > 0$. The direct, indirect and total rebound effects may be calculated for different values of the elasticity of substitution as follows (see Table 1). Under a low elasticity of substitution, the direct rebound effect is increasing with the substitution elasticity. On the other hand, the indirect rebound effect is decreasing with σ. But, both direct and indirect rebounds are positive and their sum is always equal to one.
- In a next set of figures, the elasticity of substitution is equal to one ($\sigma = 1$) since ($\rho \longrightarrow 0$), and CES function reduces to a Cobb-Douglas function. In this case, the rebound effect is generated only through the service G because we have $RE_{direct} = 1$ and $RE_{indirect} = 0$.
- In the high elasticity case ($\sigma > 1$ when $-1 < \rho < 0$), the direct rebound effect is greater than one and the indirect rebound effect is negative ($RE_{direct} > 1$and $RE_{indirect} < 0$).
- When the energy services G and Q are perfect substitutes, with $\sigma \longrightarrow \infty$, since $\rho = -1$, the direct rebound effect becomes very important and the indirect rebound effect is negative and equal to the direct rebound.

Table 1: Variation of the rebound effects with substitution elasticity

elasticity of substitution (σ)	0.1	0.5	0.9
REdirect	0.55	0.75	0.95
REindirect	0.45	0.25	0.05
REtotal	1	1	1

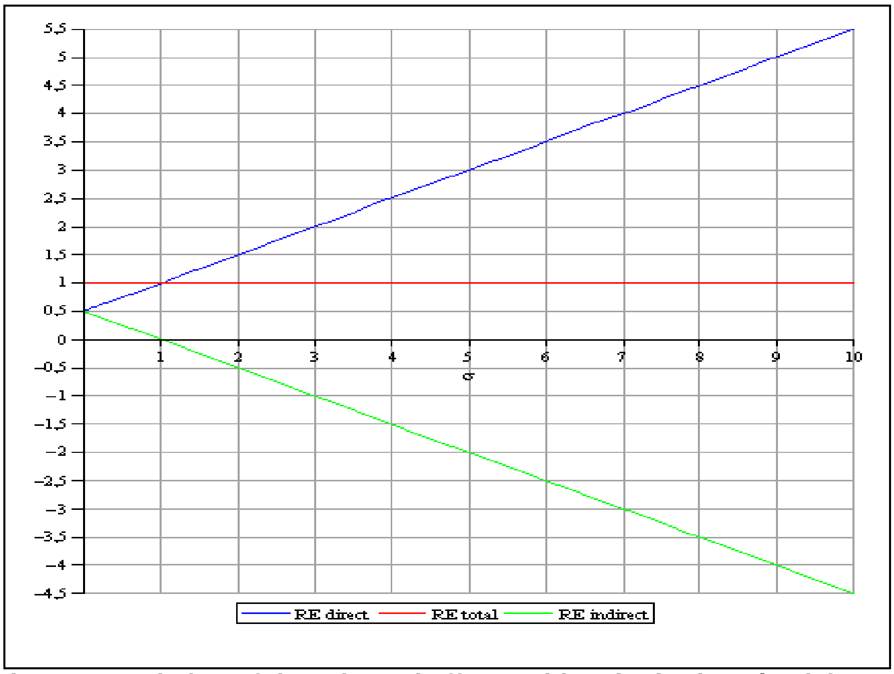

Figure 1: Variation of the rebound effects with substitution elasticity

4. Concluding remarks

The present paper explores the rebound effects from an economist's viewpoint by applying a general equilibrium modeling with three goods to quantify these effects on household energy consumption.
First, improvements in energy efficiency make energy services cheaper, and therefore encourage increased consumption of those services. This so-called direct rebound effect offsets the energy savings that may otherwise be achieved.

We determine an analytic measure of the direct rebound effect. Then, we show that this measure may be expressed as efficiency elasticity and price elasticity, which are used by Khazzoom (1980) and other various authors to capture empirically the direct rebound effect.
Second, an increase in energy efficiency of a one particular appliance leads to an increase in the energy consumption of the other appliances and goods. This is called the indirect rebound effect which may be measured through the efficiency elasticity of the demand for the other goods energy services.
Third, the price effects and income effects are the prominent mechanisms accounting for these direct and indirect rebound effects. Further, price effects due to reduced variable costs of energy services and income effects due to the redirection of saved money to other consumption have been expressed analytically and quantified.
Finally, on the basis of our theoretical discussion and numerical simulation, we show that the size of direct and indirect rebound strongly depends on the elasticity of substitution between energy services.

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Towards an Evaluation Framework for Appliance Standards, Labeling, and Incentive Programs in China

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Abstract

China's standards and labeling programs have grown rapidly in recent years with mandatory minimum efficiency performance standards and mandatory labeling requirements for 45 products and 23 products, respectively. China has also implemented a number of incentive programs such as the Rural Area Household Appliance Subsidy and Highly Efficient Products Discount which both drove an increase in energy-efficient appliance sales. However, China lacks a framework to evaluate the savings of these standards, labeling, and incentive programs. Furthermore, China has not set aside a budget to perform such evaluations, even though they will likely play an increasingly critical role in China's energy efficiency policy making as energy intensity targets become increasingly difficult to hit and the government needs to understand which policies are most effective at increasing efficiency. In order to recommend evaluation methodologies for China, we have reviewed frameworks in the U.S. (federal and state level), E.U., and Australia and identified key methodologies and related data requirements. This paper provides an overview of ex-ante and ex-post evaluation types for standards and labeling, with discussion on baseline setting as well as correction factor and compliance rate adjustments. For incentives, gross savings and net savings approaches are addressed, including an explanation of free ridership. Finally, we look at China's data availability in order to select or adapt appropriate methodologies such that they can carry out an evaluation of the energy savings from various standards, labeling, and incentive programs.

1. Introduction

Governments around the world are undertaking energy efficiency program evaluations with similar motivations but varying levels of budget and data collection. While data are the foundation of evaluation, primary data collection can be costly, and many organizations rely on secondary sources for the majority of their data needs. As China ramps up its efforts in energy efficiency in the 12th Five Year Plan[1] and beyond, data availability for program evaluation is becoming an increasingly relevant question. In particular, China's programs for mandatory standards and categorical labeling have grown very rapidly to cover 45 products and 23 products, respectively, and a number of incentive programs (Energy-Efficient Products for the Benefit of the People, Rural Area Household Appliance Subsidy, and Highly Efficient Products Discount) have led to increased sales of energy-efficient appliances [1]. In this paper, we describe the methodologies and associated data inputs for the evaluation of standards, labeling, and incentive programs and perform an initial assessment of the availability and uncertainty of those data inputs in China.

Section 1 describes the relationship of evaluation goals, data uncertainty, and budget availability in order to provide some background for key decisions that China will make as it continues to improve its capabilities in program evaluation. Section 2 highlights key findings from Lawrence Berkeley National Laboratory's (LBNL) recent review of methodologies used in different countries around the world (U.S., E.U., and Australia) to evaluate the impact (energy savings) of standards, labeling, and incentives programs [2]. Section 3 provides the key data requirements for those methodologies, an

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[1] Following on the success of the energy intensity target of the 11th Five Year Plan and in support of the 2020 target to reduce carbon intensity by 40-45% below 2005 levels, the State Council set forth new intensity targets for the 12th Five Year Plan (2011-2015). Under the new targets, energy intensity (energy consumption per unit of GDP) will be reduced by 16% and carbon intensity (carbon emissions per unit of GDP) will be reduced by 17% below 2010 levels by the end of 2015.

assessment of China's data availability, and three methodology options for China to consider in light of their data availability.

2. Data and uncertainty issues for program evaluation

There are strong relationships among the goals, data availability, uncertainty, and budget resources for any program evaluation process. As shown in Figure 1, the data inputs and algorithms used are usually determined by the goals and scope of the evaluation. Data inputs come from both primary and secondary sources collected from a wide range of literature and surveys of stakeholder groups, including consumers, manufacturers, and retailers. Each data source will carry with it an associated uncertainty, and each data input will have a relative sensitivity on the output of the evaluation algorithm. The organizations carrying out these studies should place an emphasis on measuring these levels of uncertainty and sensitivity in order to best serve the goals of the energy efficiency programs that they are implementing.

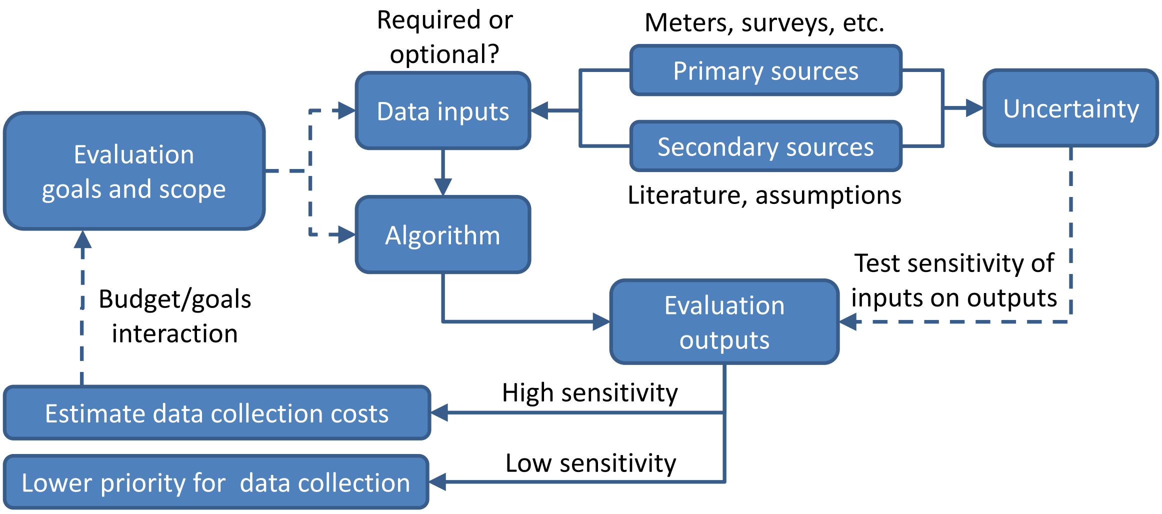

Figure 1: Interaction between goals, data, uncertainty, and budget for program evaluation

In the U.S., utilities are often seeking to determine energy savings, peak demand reductions, or market transformation of energy efficiency programs and, in turn, calculate the cost effectiveness of dollars spent on those programs. Cost-effectiveness mandates have driven evaluators to often spend additional money on data collection and evaluation in order to reduce uncertainty and improve estimates of energy savings. In China, program evaluation does not yet have these cost effectiveness mandates, but China's first demand-side management regulations were only set in place at the beginning of the 12th Five Year Plan (i.e., 2011). China's energy intensity and carbon intensity goals are providing an additional impetus for implementation and accurate impact evaluation of a growing number of energy efficiency programs.

In addition to determining the goals of any program evaluation, the scope of the process should also be outlined in terms of what measures (or products) were covered, what delivery strategy was used, and what impacts were expected in the design of the standard and program. For instance, determining the energy savings from a rebate program for compact fluorescent light (CFL) bulbs, the market transformation from a voluntary labeling program for refrigerators, or peak demand reduction for a retrofit program for commercial central air conditioning units are all viable scopes for program evaluation. Once the scope has been set, then the required data inputs and appropriate algorithms can be determined as shown in Figure 1. In evaluations, both primary and secondary data sources are used for collecting data: for example, reviewing engineering literature for estimating savings, or conducting surveys to collect hours of usage for a particular product.

All data sources, primary or secondary, will carry with them an associated degree of uncertainty. This uncertainty should be estimated. Additionally, the sensitivity of altering each input on the output should be tested using Monte Carlo simulation or some other estimation methodology. Together, the uncertainty and sensitivity of various data inputs can help determine where efforts and budget should be spent to improve data inputs and in turn improve the end accuracy of any evaluation or standards development. If energy efficiency goals are present, then this type of analysis enables the assessment of whether those goals were met or not.

In the U.S., risk analysis has been performed for utility-sponsored energy efficiency programs to identify which programs' energy savings estimates have the highest uncertainty [3]. The uncertainty of the savings for each program will depend on the uncertainty for each data input for that program's energy savings algorithm. For example, in this case, the following energy savings evaluation algorithm was used:

$$\Delta kWh_{lifetime,net,measure} = units \times \frac{\Delta kWh_{gross}}{unit} \times NTG \times EUL$$

- ΔkWh$_{\text{lifetime, net, measure}}$= Net energy savings
- ΔkWh$_{\text{gross}}$/unit = Gross energy savings per measure (unit savings)
- Units = number of measures (count)
- NTG = net to gross ratio[2]
- EUL = effective useful life[3]

Table 1: Primary and secondary data sources for standards development and program evaluation, adapted from [4]

	Primary data sources							Secondary data sources		
	Direct measurement (metering)	**Laboratory test data**	**Manufacturer surveys**	**Program participant surveys**	**Retailer surveys**	**National energy surveys**	**Government statistics**	**Energy/evaluation literature**	**Deemed values**	**Simulation and modeling**
Usage	X					X		X		
Unit energy consumption	X	X	X			X		X	X	X
Existing stock, saturation						X	X	X		
Lifetime	X		X	X		X		X		
Sales/shipments (real or forecasts)			X		X		X			
Site-to-source energy conversion factors							X	X		
Emission factors							X	X		
Free ridership				X				X	X	
Compliance		X								
Number of participants, non-participants				X				X		
Participant spillover				X				X		
Market effects				X				X		
Heating and cooling degree days							X	X		

[2] The net-to-gross (NTG) ratio determines the actual energy savings attributable to a particular program, as distinct from energy efficiency improvements that would have occurred without the program. The NTG ratio equals the program's net energy savings divided by the program's gross energy savings. Factors such as free ridership, participant spillover, and market effects contribute to NTG ratios according to varying definitions. More description is available in section 3.1.3.
[3] The effective useful life (EUL) of a measure (i.e., measure lifetime) is the period of time that the measure is expected to perform its intended function in a typical installation [19].

The number of measures (count), gross energy savings per measure (unit savings), and net-to-gross ratio all have uncertainty. In California, there is an impetus for the utilities to ensure that their energy savings are credible and reliable (not just estimated) given energy efficiency targets and cost-effectiveness mandates (getting the most efficiency with the least amount of money). In China, there are energy efficiency targets, but explicit cost-effectiveness mandates do not yet exist and estimated savings are acceptable. Given the limited budgets for evaluation in China, however, it is essential that only the most critical issues influencing the estimated savings be investigated – for example, the data issues that bring the most uncertainty (data sources, data types, program implementation methods, etc.). As energy efficiency targets become harder and harder to meet (with potentially the added pressure of tighter budgets), this type of risk and uncertainty analyses will help China focus on conducting accurate and credible evaluation studies, aiding future policy decisions and enabling cost-effective energy savings. If it is found that a certain data input has high uncertainty and sensitivity on the final output, then funds should be allocated for collecting additional primary data that would reduce that uncertainty. The impetus for that particular budget, however, must originate from the need for accurate and credible evaluations [4].

Table 1 outlines the common primary and secondary data sources used in program evaluation. While secondary sources largely consist of existing literature (including technical resource manuals) and simulations, primary sources involve metering and surveys of manufacturers, retailers, and consumers (participants). Additionally, some governments carry out national energy surveys, such as the Residential Energy Consumption Survey (RECS) that is used to gather socio-demographic data and energy usage in homes across the U.S.

3. International review of evaluation methodologies for standards, labeling, and incentives

This section provides a quick overview of impact evaluation methodologies and outlines key evaluation studies performed to date on appliance standards, labeling, and incentives in the U.S., E.U., and Australia.

3.1 Common methodologies in impact evaluation

The basic research question in impact evaluation is: What were the true effects produced by a program or intervention in terms of energy savings (as well as other impacts, such as changes in electricity demand and carbon emissions), separated out from what would have otherwise occurred absent the program or intervention? The recent international evaluation framework review prepared by LBNL referenced over 60 evaluation studies from the U.S., E.U., Australia, and other countries, and it examined 30 studies in depth for unique evaluation methodologies [2]. In general, evaluation of standards, labeling, and incentives follow a similar methodology, which is summarized in Figure 2 and can be broken down into three main parts: 1) stock model (steps 1-3), 2) baseline setting (step 1), and 3) *ex-post* evaluation options (steps 4-7).

3.1.1 Stock model

Ex-ante evaluation of appliance standard programs plays a large role in a number of countries' standards development process, whereby the impact on national energy demand can be estimated for different levels of proposed standards – essentially, different unit energy consumption (UEC) levels against the same baseline (step 1). The unit energy consumption (UEC_e) for the unit replacing or displacing the baseline unit can be gathered from engineering specification documents from the manufacturer. Subtracting UEC_e (energy use of the energy-efficient product) from UEC_b (energy use of the product in the baseline) under the correct usage conditions will give the per unit energy savings (step 2). The usage of the old and new products may vary in certain cases. Unit energy savings can be multiplied by the number of measures or units sold to calculate gross savings (step 3). Shipment projections are used to estimate the "number of measures," the number of products that will be sold under a new standard or labeling program. In the case of incentive programs, the "number of measures" typically mirrors the number of rebates given out for more efficient appliances.

These elements (UEC and number of measures) compose what is typically called an engineering-based model or a stock model in the literature. For the purposes of streamlining these calculations for large numbers of products and product groups, spreadsheet models are usually developed to track product vintage, efficiency, hours of use/lifetime, price, and other factors. Stock model methodologies do not vary widely for appliances. Typically, the model is simply an interaction between the existing stock, sales, and retirement of appliances, and their related energy consumption over time [5, 6].

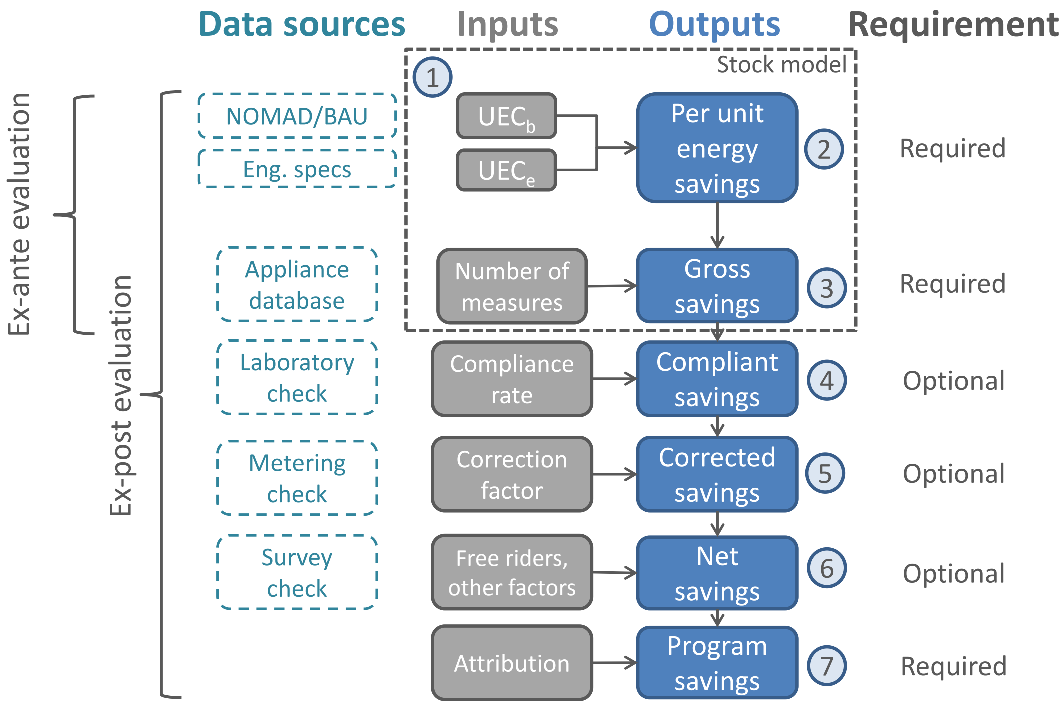

Figure 2: *Ex-ante* and *ex-post* evaluation frameworks for standards, labeling, and incentives

3.1.2 Setting the Baseline

Baselines can be set to estimate some initial level of market penetration for high efficiency products in the absence of standards or labeling. Setting the baseline against which energy savings are measured is one of the most important steps in program evaluation. Since standards, labeling, and incentive programs are all seeking to push more efficient appliances and products into the market, the questions regarding the baseline include the following:

- What is the efficiency of the products that they are replacing or displacing?
- What would have been purchased if the program had not been put in place?
- What would manufacturers have produced and retailers stocked without appliance standards?
- What type of refrigerator would a consumer have purchased without a rebate for a more energy-efficient model?

Setting baselines for standards evaluation is becoming more difficult. There is no longer much data on autonomous efficiency improvements over time in many countries, as standards and labeling (S&L) programs have increased in number. While the proliferation of these programs is good for energy efficiency, it does make setting baselines somewhat of a guessing game, although methodologies are improving. In general, standards evaluations have three baseline setting techniques to choose from:

1. Frozen baseline: the efficiency of new products remains constant in the base case
2. Improvement baseline: where historic UEC data exist, the efficiency of new products improves at a similar rate of historic autonomous efficiency improvement, declining into future
3. Market share baseline: where data on market share for models of different efficiencies exist, a baseline efficiency can be estimated for future years[4]

[4] An additional baseline setting methodology using Bass curves to describe market adoption is discussed in [1]

Frozen baselines have typically been used when there is a lack of data on market-driven improvements, as is typically seen in many developing countries. The China National Institute of Standardization (CNIS), the technical body responsible for developing standards and managing the mandatory energy labeling program, also uses frozen baselines in its annual white papers that have projections on the potential savings from new minimum energy performance standards (MEPS) on various products [1]. Improvement baselines have been used in a few cases; for example, they were used in the case of a recent, comprehensive evaluation of standards and labeling (S&L) programs for refrigerators in Australia [7], where high quality data on shipments were available. As shown in Figure 3, various S&L programs have had distinct impacts on the efficiency of refrigerators sold, including the first mandatory labeling implemented in 1986, updated labeling and MEPS implemented in 1999, and updated MEPS implemented in 2005. Finally, market share baselines have been used in the *ex-ante* evaluation of potential standards levels for U.S. federal standards. For example, given that ENERGY STAR now plays a significant role in the evolution of appliance energy efficiency, it is often taken into account when forming a baseline. Typically, the U.S. Department of Energy (DOE) will work with the U.S. Environmental Protection Agency (EPA) to come up with estimates of where the ENERGY STAR market share of a particular appliance is heading in the absence of standards [6].

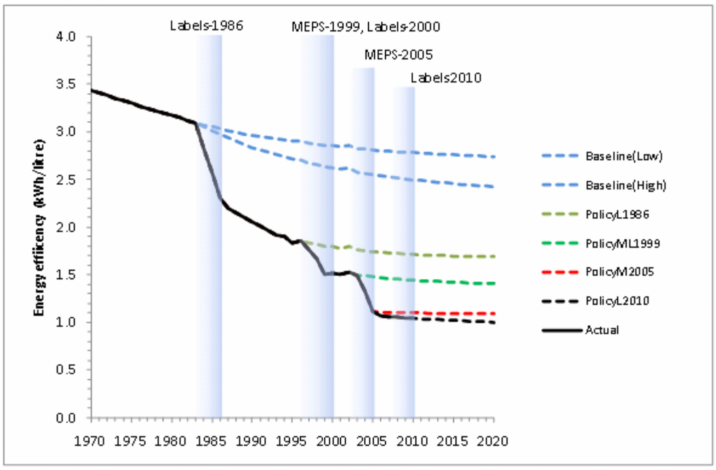

Figure 3: Average efficiency of top-mount refrigerator-freezers under different policy scenarios
Source: [7]

3.1.3 Ex-ante and ex-post evaluations

Ex-ante evaluations are quite common for appliance standards, since they help prove the case for energy efficiency, in both reducing a country or state's energy demand and likely saving consumers money in the process. These evaluations take on many assumptions about appliance performance in the field, however, and there is a growing interest in correcting *ex-ante* evaluations with field data to achieve more accurate savings estimates through the use of correction factors. Finally, *ex-post* evaluation of incentives offers the option to include free ridership, reflecting the fact that some consumers would have purchased a more efficient appliance in the absence of an incentive, as well as program spillover, since some customers install additional energy efficiency measures, whether or not they participate in a program.

Appliance efficiency may vary widely in the field due to a number of factors. For example, the UEC_e that is used in *ex-ante* evaluation is often based on engineering specifications as claimed or declared by the manufacturer. In many countries, these specifications are verified by third-party laboratory testing, but not all countries have product testing, and non-compliant products may still exist even where testing is done. Verification testing can be done on a sample of products to get a representative compliance rate (step 4 in Figure 2), and test for how laboratory performance might differ from claimed performance (as shown in Figure 4). In fact, reliable data on compliance rates are not that widely available in many places around the world, so many program evaluations often skip this step. Alternatively, metering measurements could be taken on an appliance once it is installed in a home or commercial building, and then installed performance could be compared with claimed performance to get a representative correction factor (step 5). A recent study at LBNL explored this issue in depth [8].

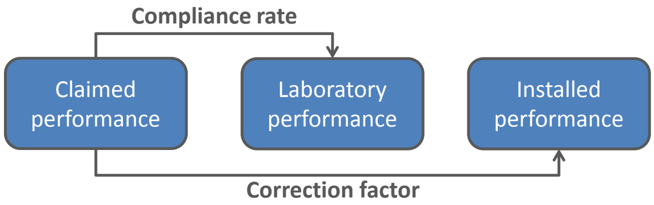

Figure 4: Relationships of compliance rates and correction factors to performance data

Net savings adjustments (step 6) are common for incentive evaluations and include combinations of estimates for free riders, participant spillover, and market effects. One of the most important concepts to understand within a technical measurement approach is that net savings is a behavior metric that adjusts gross savings to account for how a program influences the decision-making processes of the participants or people in the marketplace. In the case of free riders, the original baseline will account for the product being replaced or displaced, while the free rider proportion will account for those participants who would have gone ahead with purchasing a more efficient product even without the incentive that was offered. Participant spillover will account for additional energy saving actions that the participants may have made due to the incentive program. Market effects evaluations estimate a program's influence on encouraging future energy efficiency projects because of changes in the marketplace. The evaluation focuses on the changes in the structure or functioning of a market, or the behavior of participants in a market, that results from one of more program efforts [9, 10].

In the last step, a specific savings amount has to be attributed to a specific program (step 7). This is important when there are various programs that overlap in their influence on one sector's energy efficiency. It is common for labeling and incentive programs to have some overlap, for instance, since both programs are pushing the consumer to purchase an above average efficiency product. Like free riders, attribution factors are also calculated using some mixture of surveying and expert input.

Not depicted in Figure 2 are site-to-source energy conversion factors and emissions factors, which help to determine primary energy savings and emissions savings once secondary energy savings have been determined from the evaluation. Site-to-source energy conversion factors differentiate between primary and secondary energy use and efficiency, which the U.S. EPA has a standardized definition for: "When primary energy is consumed on site, the conversion to source energy must account for losses that are incurred in the storage, transport and delivery of fuel to the building. When secondary energy is consumed on site, the conversion must account for losses incurred in the production, transmission, and delivery to the site. The factors used to restate primary and secondary energy in terms of the total equivalent source energy units are called the source-site ratios" [11]. Once the quantity and type (coal, natural gas, oil, etc.) of primary energy or source energy units is known, then a carbon dioxide emissions factor can be used to find the associated carbon emission savings for the energy saved. Similar emissions factors could be used to determine the amount of emissions avoided for other common air pollutants including sulfur dioxide, nitrogen oxides, and ozone.

3.2 Review of international impact evaluation studies

3.2.1 United States – Federal level

LBNL has conducted a number of national impact assessments for standards for major residential and commercial appliances, using dynamic Business-as-Usual (BAUs) scenarios where assumptions were made on baseline efficiency improvements over time in the absence of new standards. The data for making these assumptions came from a mixture of sources including trade associations (e.g., the Association of Home Appliance Manufacturers) and U.S. DOE Technical Support Documentation (TSD) for related appliance standards development [6, 12, 13, 14]. Also at the federal level, the U.S. EPA carries out impact evaluations for its certification labeling system ENERGY STAR. Key indicators such as ENERGY STAR awareness and ENERGY STAR impact on purchasing decisions are quantified through annual surveys [15]. LBNL has also conducted impact studies on the resultant energy savings from the ENERGY STAR program [16].

3.2.2 California and other U.S. States

California is a leader in energy efficiency, and as such, has developed protocols and procedures for impact and process evaluation [17, 18, 19]. Particularly in the area of incentive programs for building, appliance, and lighting efficiency, these protocols have been very helpful for program evaluators.

Alongside the development of protocols, the evaluation community in California developed the Database for Energy Efficient Resources (DEER) that contains "deemed savings" values for efficiency measures that are commonly installed in the marketplace. California has also established codes and standards in product areas that are not covered by federal standards [20]. Additionally, they recently performed an impact evaluation of several state standards that they had implemented, which incorporated estimates for naturally occurring market adoption and compliance rates [21].

There have been a number of studies by experts at LBNL, EPA, and the American Council for an Energy Efficient Economy (ACEEE) looking at the wide range of evaluation practices found across the U.S. [9, 22, 23]. Other states have developed their own regional or state-based technical resource manuals (TRMs), similar to California's DEER database [24]. Amidst the diversity of existing methodologies given the U.S.'s diverse regulatory space for electricity and energy efficiency, there have been efforts to consolidate methodologies and potentially make a national impact evaluation protocol for various energy efficiency measures. The State and Local Energy Efficiency Action (SEEAction) Network wrote a scoping study to identify issues with developing such a protocol [25], while the National Renewable Energy Laboratory (NREL) is running the Uniform Methods Project, which has developed draft methodologies for specific efficiency measures in residential lighting, commercial HVAC, and other areas.[5]

3.2.3 Australia

Australia has had a number of efforts in the evaluation of appliance programs. In 2002, Australia created its first draft framework for the evaluation of the Australian Energy Efficiency S&L program. An additional program audit for labeling was performed in 2004/2005, with more comprehensive program audits for air conditioners and refrigerators performed as recently as 2010 [7, 26]. These studies are very helpful for their use of improving baselines and correction factors as well as their strong data collection techniques.

3.2.4 European Union

European evaluation efforts have been headlined by two recent large-scale projects in support of E.U. energy efficiency targets. The first project was the Evaluation and Monitoring for the E.U. Directive on Energy End-Use Efficiency and Energy Services (EMEEES), which focused on bottom-up methodologies for 20 different energy efficiency measures [27]. The second project was the European Energy Efficiency Database (ODYSSEE), which focused on top-down indicators for energy efficiency as a route to monitor energy efficiency trends and policy measures in Europe [27]. In addition to these two projects, a number of studies have been done to evaluate the savings from the E.U.'s categorical labeling program [29, 30].

The EMEEES methodologies covered all forms of common programs including regulation (MEPS), labeling and training measures, financial incentives, and voluntary agreements. In addition to creating bottom-up methodologies for 20 different measures, the EMEEES project also proposed a template for member states to establish National Energy Efficiency Action Plans (NEEAPs) and a methodology for the E.U. Commission to perform *ex-ante* assessments and *ex-post* evaluations of the NEEAPs. The summary report for the EU's EMEEES project argued that top-down methodologies are accurate enough for appliances and vehicles, if there were well defined statistical indicators of average specific energy consumption per unit, while bottom-up methodologies were difficult due to free rider and multiplier effects which can be very costly to quantify.[6] If the measure saved more than 40 million kWh in annual electricity savings, more than 100 million kWh in annual energy savings, or greater than 5% of any individual member state's Energy Services Directive target, bottom up methodologies were justified. If a member state had only limited data about the measure, they used EU default values. If a member state had very measure-specific data, then there were specific harmonized guidelines they could follow to calculate the savings [31].

For a full list of other countries and program evaluation studies reviewed, see [2].

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[5] More information on NREL's Uniform Methods Project can be found at: http://www.nrel.gov/extranet/ump/about.html

[6] While bottom-up evaluation relies on surveys and quantification (of participants and specific measures) to inform inputs into engineering-based models, top-down evaluation uses aggregate consumption indicators (such as total energy consumption or per-capita energy consumption) as inputs to macro-economic demand models.

4. Program evaluation options for standards, labeling, and incentives

This section provides the key data requirements for the methodologies reviewed in section 3, an assessment of China's data availability, and three methodology options for China to consider in light of their data availability for standards and labeling evaluations as well as incentive evaluations.

For the three methodology options, the first is largely based on China's existing capabilities and data availability. The second option proposes a small budget increase to conduct some data collection that will improve results and reduce uncertainty for the related analysis, with the idea that this option could be implemented on a shorter time scale of one to three years. The third option is a long-term implementation (five to ten years) of a number of improved data collection methods to achieve the lowest uncertainty with an effective use of budget.

Whether or not the Chinese government seeks to move towards these options that involve increased data collection and may require additional funds depends on their goals in the energy efficiency space. For instance, additional budget for surveying and metering may yield more certainty in the energy savings estimates from incentive evaluations. A full assessment of China's data availability will certainly aid the Chinese government's efforts in energy efficiency planning as they continue to improve their rapidly expanding standards, labeling, and incentive programs.

4.1 Key data requirements and China data availability

Table 2 outlines the data types needed for evaluations of standards, labeling, and incentive programs. The bolded items indicate which data types that China is already collecting through surveys and other types of data collection [1]. The shaded items are those data types that are optional in some cases. For instance, in the evaluation of incentives, free ridership is not needed for a gross energy savings evaluation but is required for a net energy savings evaluation. The levels of uncertainty and sensitivity have been estimated for this preliminary study based on the authors' knowledge of evaluation literature and familiarity with Chinese data availability. These hypothesized levels can later be tested once formal program evaluations are underway in China.

Associated with each data type is an assigned sensitivity based on that data's impact on the evaluation algorithm. Previous ex-post evaluations have shown that number of measures, unit energy savings, and net-to-gross ratio have the highest impact on the end result [3]. As such, those options have all been flagged as high sensitivity in Table 2. Each data type also has an assigned uncertainty based on the currently used data source. For example, the annual UEC data currently collected by the China Energy Label Center (CELC) are a combination of the unit's efficiency (since energy labeling is now mandatory for many consumer products, these data must be reported by the manufacturers to CELC) multiplied by some assumption on usage. Although there is low uncertainty about the declared unit efficiencies, there could be higher uncertainty on the usage of the product (air conditioner usage varies widely, for instance).

Table 2: Data types required for standards, labeling, and incentives evaluation with China's current data sources and associated uncertainty and sensitivity

Data type	Standards, labeling, incentives? (S,L,I)	Data source	Sensitivity (high, medium, low)	Uncertainty (high, medium, low)
Annual energy savings per unit product	S, L, I	CELC white paper, assumptions	High	Medium
Existing stock	S, L	Calculation	Low	Low
Market saturation (ownership, market shares)	S, L	China Statistical Yearbook	Medium	Low
Lifetime or retirement function	S, L, I	Literature, assumptions	Medium	Medium
Future shipment forecasts	S, L	Assumptions, calculation	High	Medium
Usage adjustment factor (UAF)	S, L, I	Literature, assumptions	Medium	Medium

Naturally occurring market adoption	S, L	Estimation	Medium	Medium
Compliance rate	S, L, I	Literature, assumptions	Medium	Medium
Real shipments/sales	S, L	CELC white paper	High	Low
Site-to-source energy conversion factors	S, L, I	Literature, assumptions	Medium	Low
Emission factors	S, L, I	Literature, assumptions	Medium	Low
Number of measures	I	Ministry data (e.g. Ministry of Finance)	High	Low
Free ridership	I	Survey needed	High	High
Participant spillover	I	Survey needed	Medium	Medium
Market effects	I	Survey needed	Medium	Medium

Note: bolded data types are for data that China has already collected, shaded data types are optional in some cases.

As mentioned in section 2, once the sensitivity has been determined, this can assist in deciding priorities for enhanced data collection. Here, we add the uncertainty as an additional parameter to help determine data collection priorities. Table 3 outlines the high, medium, and low priorities for data collection based on sensitivity and uncertainty parameters. For instance, if an input has a high sensitivity on the evaluation algorithm but a very low uncertainty based on the current data source, then it is a low priority for improved data collection methods. Table 2 shows that real sales for products have a high sensitivity for standards and labeling evaluation but a low uncertainty. Sales has perhaps the largest impact on the evaluation algorithm (thus the high sensitivity), but China has had data collection in place for about three years now via a retail sales survey company, so this would be a relatively low priority for any new or improved data collection. As another example, lifetimes of products can help in projecting sales or in determining useful life of a product and thus carry a medium sensitivity. The data are currently estimated based on international literature giving them a medium uncertainty since product lifetimes within China may vary from those in the U.S. or E.U.

Table 3: Relationship of sensitivity and uncertainty of data inputs to data collection priority

Uncertainty / Sensitivity	High	Medium	Low
High	High priority	High priority	Low priority
Medium	Medium priority	Medium priority	Low priority
Low	Medium priority	Low priority	Low priority

4.2 Identifying evaluation options for China

Identifying where China current collects data will aid in recommending options for China for evaluations that it can currently carry out with little or no additional data collection. Assigning sensitivity and uncertainty to all other data types will aid in recommending options for evaluation that it can carry out in the short-term (1-3 years) and long-term (5-10 years) based on expanded and improved data collection. In this section, we identify evaluation options for China for standards and labeling as well as incentive programs. We outline three options based on: 1) current capabilities, 2) increased but limited data collection over the next few years, and 3) a more expansive increased data collection over the next five to ten years.

4.2.1 Standards and labeling options

The three options for standards and labeling evaluation are as follows:

1. Ex-ante or simple ex-post evaluation based on existing capabilities (to implement now)
2. Ex-post evaluation with improved data on product usage, compliance, and site-to-source factors (to implement on a 1-3 year time scale)
3. Full ex-post evaluation with expanded surveying, testing, and/or metering (to implement on a 5-10 year time scale)

Within each option (outlined in Table 4), there is a specific direction for each data source:

1. Literature: Pull data from domestic or international literature
2. Existing data: Use data sources that China has already collected, including the China Energy Label Center's annual white paper
3. Datasets: Use a dataset that China should have at a future date (e.g. emissions factors)
4. Survey/metering: Employ new survey, laboratory testing, or on-site metering to gather new and improved data

Table 4: Data sources for standards and labeling evaluation options

Data type	**Implement now**	**Short-term (1-3 years)**	**Long-term (5-10 years)**
Annual energy savings per unit product	Existing data	Survey/metering	Survey/metering
Market saturation	Existing data	Existing data	Existing data
Lifetime	Literature	Literature	Survey/metering
Usage adjustment factor (UAF)	Exclude	Exclude	Survey/metering
NOMAD or other baseline	Exclude	Exclude	Datasets
Compliance rate	Exclude	Datasets	Survey/metering
Real shipments/sales (or forecasts if *ex-ante*)	Existing data	Existing data	Existing data
Site-to-source energy conversion factors	Literature	Datasets	Datasets
Emission factors	Literature	Datasets	Datasets

Note: Exclude means that data point is not needed for the specified analysis in this option.

Option 1 is roughly based on China's current evaluation capabilities and data availability and, therefore, does not involve any expanded surveys. Unit savings, market saturation, and sales can be taken from CELC's existing databases and retail surveys. All ex-post evaluation adjustments (such as usage adjustment factor and compliance rates) are excluded. Site-to-source energy conversion factors and emission factors can be estimated with existing domestic literature, such as project design documents reported under the Clean Development Mechanism.

Option 2 makes two major changes from Option 1. First, there would be a set amount of surveying or on-site metering to determine hours of usage for various products (e.g. lighting, televisions, air conditioners, etc.). This would help decrease the uncertainty surrounding the high sensitivity data point on unit energy savings but would also carry an associated need for budget to finance that surveying or metering. Second, new estimates could be made on compliance rate and emission factors based on expanded datasets that China is likely to have in one to three years. For example, China is currently expanding its product verification testing (within CNIS's Energy Efficiency Laboratory Division) and may have an expanded dataset on product compliance in the coming years. Additionally, with China's expanding reporting for carbon intensity targets and growing carbon market programs, data on emission factors will likely improve over the coming years.

Option 3 suggests a full set of evaluation capabilities, the extent of which is even beyond current evaluation scopes in the U.S., E.U., and elsewhere. The main difference in going from option 2 to option 3 is in using more sophisticated ex-post evaluation adjustment factors, including usage adjustment factors, compliance rates, and baselines. Through a mixture of laboratory testing and on-site metering, China can get a more accurate energy savings estimate by comparing how products perform in the field versus how they are declared to perform by manufacturers. It should be noted, however, that extensive testing like this is not yet regularly performed for ex-post evaluation in major developed countries due to the high budget required. There will always be a balance between budget and certainty, and China should make appropriate decisions based on their evaluation goals. For baselines, China will have enough data to perform a more sophisticated baseline analysis given that it will have collected 10-15 years of retail sales data broken down by energy efficiency labeling level.

4.2.2 Incentives options

Unique data points for an incentives evaluation (as compared to a standards or labeling evaluation) are highlighted in Table 5. The options for evaluation follow a similar categorization.

1. Simple ex-post gross savings evaluation based on existing capabilities (to implement now)
2. Ex-post net savings evaluation with improved data on free ridership and unit energy savings (to implement on a 1-3 year time scale)
3. Full ex-post net savings evaluation with expanded surveying on free ridership, participant spillover, and market effects (to implement on a 5-10 year time scale)

Table 5: Data sources for incentives evaluation options

Data type	Implement now	Short-term (1-3 years)	Long-term (5-10 years)
Annual energy savings per unit product	Existing data	Survey/metering	Survey/metering
Number of measures	Existing data	Existing data	Existing data
Free ridership	Exclude	Survey/metering	Survey/metering
Participant spillover	Exclude	Exclude	Survey/metering
Market effects	Exclude	Exclude	Survey/metering

Note: 'Exclude' means that data point is not needed for the specified analysis in this option.

China has implemented a number of rebate programs for energy efficient products in the past few years including Rural Area Household Appliance Subsidy Program (also known as "Appliances to the countryside") and Energy Efficient Products Discount Program (also known as "Huimin gongcheng") [1]. Evaluations for gross energy savings can be performed on these programs by simply multiplying the number of rebates by the unit energy savings and expected useful life of the product. This assumes, however, that all of the measures or efficient products were successfully installed which may not be the case. Inspections and surveying could be performed on a selection of sites to determine the proportion of measures installed to rebates granted. For a net energy savings evaluation, a survey will be needed to evaluate the amount of free ridership. Further down the line, a more sophisticated survey can be administered to estimate other values including participant spillover and market effects. The degree to which these values are used in estimating net-to-gross ratios in ex-post evaluation varies widely in the U.S. Additionally, there is a concern that with a proliferation of energy efficiency policies (standards, labeling, incentives, other awareness campaigns) impacting any one consumer's purchase, it may become increasingly difficult to attribute the savings from an energy-efficient product to any one incentive program [9].

5. Conclusion

As China ramps up its efforts in energy efficiency in the 12th Five Year Plan and beyond, data availability for standards development and program evaluation is becoming an increasingly relevant question. In this study, we have surveyed international evaluation methodologies and recommended options for China to improve its capabilities in program evaluation. In order to establish the foundation of these recommendations, we first outlined the relationships between program goals and budget, choice of algorithm and methodology, data gathering, and data sensitivity and uncertainty. Improvement to data inputs should be prioritized based on how much those inputs impact the end result of the analysis (sensitivity) and an assessment of data quality and collection method (uncertainty). Given the scope of China's appliance standards, labeling, and incentive programs and the scale of energy consumption growth in this sector, improvements to practices in development and evaluation should continue to be recommended. We found that data types with high sensitivity and high or medium uncertainty should be prioritized for increased or improved data collection in the medium term (1-3 years). Both annual energy savings per unit and free ridership fit this description, and China can plan increased surveying and metering to reduce the uncertainty of these values. Any increased data collection will need extra budget and human resources, which may be difficult for CNIS to manage. A small-scale surveying and metering pilot program could be introduced as a near-term, low budget option for China to test out how China might improve its evaluations and decrease the uncertainty of energy savings achieved by its expansive standards, labeling, and incentive programs.

Acknowledgments

We would like to express our deep appreciation to the China Sustainable Energy Program of the Energy Foundation and the Collaborative Labeling and Appliance Standard Program (CLASP) for providing funding for this project. We would especially like to thank Kevin Mo and Steven Zeng. This work was supported by the China Sustainable Energy Program of the Energy Foundation and the

Collaborative Labeling and Appliance Standard Program (CLASP) through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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An econometric model to assess residential electricity savings in the EU

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Abstract:

For policy makers at the European and national level it is important to know how effective energy policies and measures are and how much energy has been saved, in particular towards the 2020 energy saving target. Alongside the evaluation of the energy savings, it is also necessary to collect as much information and knowledge as possible about energy consumption trends and factors influencing energy consumption. Moreover, for policy makers it is crucial that a monitoring and evaluation method is giving good and reliable results on the one hand and is relatively easy and straightforward to use in practice on the other hand. In the paper a new methodology for quantifying the energy savings produced by energy efficiency measures and policies is described. The methodology is based on a relatively simple econometric model that is used to estimate consumption and, based on that model, to forecast energy consumption. The forecasted consumption is then compared with the actual consumption. The differences between the forecasted and the actual consumption can be interpreted as the estimated energy savings.

We present a general energy demand model which is used to evaluate energy savings due to energy efficiency policies. The general model can be applied to different sectors (e.g. residential, tertiary) and different fuels (e.g. electricity, gas). In this paper the model is applied to the residential electricity sector.

Based on the econometric model, the energy savings are estimated for six Member States. The results show that energy efficiency policies are already starting to be successful and their impact on energy consumption is already visible in the analyzed MSs, which achieved important savings in consumption.

1. Introduction

Energy efficiency has become one of the main policy goals in the European Union. Many important directives and regulations to promote energy efficiency have been implemented or are in the planning phase just before implementation. Furthermore a lot of EU Member States have been very active in the area of energy efficiency on the national level, having implemented many important policies and measures. For the policy maker at the European and national level it is therefore important to know how effective these measures are, where the different countries stand in terms of energy efficiency, and how they compare to each other. A monitoring and evaluation system is needed. Alongside the evaluation of these policies, it is also necessary to collect as much information and knowledge as possible about energy consumption trends and factors influencing energy consumption. In this project we build a methodology to evaluate energy efficiency improvements of a country by quantifying the energy savings produced by energy efficiency measures and programmes. For policy makers it is crucial that a monitoring and evaluation method is giving good and reliable results on the one hand and is relatively easy and straightforward to use in practice on the other hand. The methodology we are using in this project is a relatively basic econometric model that is used to estimate actual consumption and based on that model to forecast energy consumption.

The general economic model used to estimate energy demand usually includes energy prices, an indicator for the economic situation (e.g. GDP), a variable for weather/climatic conditions (e.g. heating degree days), and the population size. To this variables we add the stock of electric appliances (i.e. refrigerators). Energy demand is then estimated as a function of these factors. Based on the model, we also forecast energy demand for a pre-specified period (2 and 4 years).

The forecasted consumption is then compared with the actual consumption. The differences between the forecasted and the actual consumption are the achieved (estimated) can be interpreted as energy savings (the interpretation of this difference will be discussed in more detail in chapters 3.2. and 3.3..)
In this project we present a general model[1] that can be applied to different sectors (residential and tertiary sector) and different markets (electricity and gas) under different conditions and specifications.

2 Design of the Database

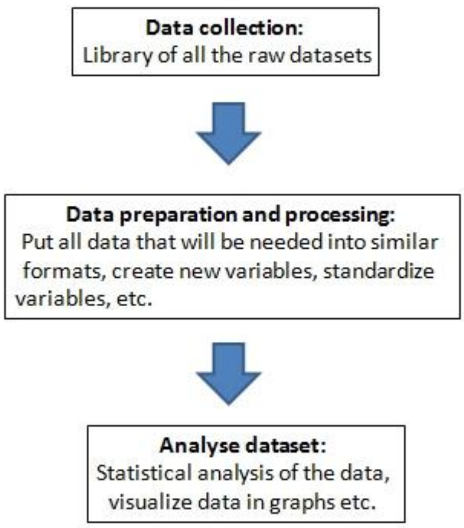
2.1 Methodology

The database is created for the econometric analysis with a statistical software programme. In this project Eviews is used but any other statistical software can be used as well. The structure of the database consists of multiple levels. The first level consists of the raw datasets (Excel files) taken from various data sources. On a second level, the relevant data needed for the model is transformed, processed and formatted for use in Eviews.[2]

The formatted data can then be analysed (statistical analysis, graphs etc.) as a preparation for the econometric analysis. The creation of the database is a crucial step in the project process as the quality of the models depends to a large extent on the data used. The statistical analysis can be found in chapter 3 as a part of the research design/methodology.

The methodology for the database design and data analysis is as follows:

Fig. 1: Database methodology



2.2 Outline of the Database

The database consists of all collected raw datasets. From these raw datasets we produced two individual excel sheets with the data needed for the econometric analysis, one for each of the two econometric models.

The following table gives an overview of the database with the collected datasets/variables that could be used for the econometric model and also for further analysis related to the project. The database is as inclusive as possible to give an overview of all relevant data. Not all datasets / variables included in the database will actually be used in the modelling process.

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[1] The models are based on the National Consumption Metrics Models developed by Marvin Horowitz.
[2] Note: The econometric analysis as described in this report is done in Eviews and hence the database is formatted for use in Eviews. However, the available, collected datasets can be used in any other statistical software.

While the geographic dimension of the dataset all EU-27 countries are included in the database, for the econometric analysis not all EU-27 Member States have been included but only certain group of countries. The Member States that have been included in the analysis depends on data availability, the choice of the regression model and the grouping of countries. The time dimension of the database is: 1990 to 2010 (2010 being the latest available year on Eurostat at the time of the project). The economic sectors coverage is the residential sector

Tab. 1: Overview of available datasets

Data Source	Dataset/ Variables
All Sectors	
Eurostat	Actual heating degree days
	Real GDP per capita
	Population
	Value added by economic sectors
	GDP deflator
Odyssee Database	Energy efficiency index
	Final energy intensity
Residential Sector	
Eurostat	Final energy consumption
	Final electricity consumption
	Final gas consumption
	Gas prices
	Electricity prices
	Number of households (per country)
	Average people per household
Odyssee Database	Stock of appliances

2.3 Data availability and quality

In general, the datasets are available for the full timeframe of the analysis from 1990 to 2010. Only the population dataset and the energy consumption datasets are complete for all Member States. The heating degree dataset is complete from 1990 until 2009 but ends at 2009, there is no data on actual heating degree days for 2010 on Eurostat at the time of the project. All other datasets are incomplete with missing observations for at least one Member State but usually for several Member States and over several periods. For data on households like the number of households per country, average people per household and average size of dwelling in square meters the datasets are very incomplete and cover only a few countries and short time periods.

The countries that are being analyzed in this project were partly also selected because of the high availability and quality of their corresponding datasets. This is true for the four bigger countries, namely France, Germany, Italy, and the United Kingdom. However, also for these countries we have incomplete datasets and/or differences in the quality of the available data. For Italy, for instance, the electricity prices for the residential sector are missing for three periods.

There are several ways to deal with missing data. One way to deal with missing data would be to pool countries together to a group and then do a panel analysis. Another way is to estimate the missing data points or extrapolate them. For some Member States there might exist a similar dataset without the missing observations in another database, e.g. a national database. However, this is only true for some countries and the different languages in the EU make it difficult to collect those data.

The quality of the available data can differ to a great extent and is closely related to the methodology of data collection. Methodologies may change over time which can cause a disturbance of the dataset. These disturbances can have significant impacts on the econometric models' results.. Apart from a change in data collection methodology, other factors can influence the quality of the data. These factors are seldom known and are difficult to detect in the data. One possibility to understand more about the quality of the data is to look at the graphs of the different datasets. If there are important outliers or very unusual trend patterns it is very likely that the quality of the data is not very high. Data quality was another determinant in order to select countries for our econometric analysis. The quality of the datasets of France, Germany, Italy, and the United Kingdom is in general relatively high compared to other countries also because these countries have a long tradition in data collection.

3 Design of the econometric models

3.1 General research outline

The aim of this project was to build a methodology that produces good and reliable energy efficiency (energy savings) estimates to evaluate if policies designed to reduce energy consumption in the EU have already been successful. Furthermore, the models have to be relatively simple to be of use in the daily practice of the policy maker for policy evaluation and further development of policies. The project presents a general model that can be applied to different sectors (residential and tertiary sector) and different markets (electricity and gas) under different conditions and specifications.

We have used two different estimation approaches to estimate the models. The first approach is to estimate individual time series models with OLS. The second approach is to estimate a panel model with country fixed effects (LSDV) including either all 27 EU Member States or, alternatively, a sub-group of countries.

The individual time series models generally deliver more precise results and smaller forecast erros whereas the panel models have more observations and hence deliver more stable coefficients less affected by multicollinearity and outliers.

We estimate different models for each of the six countries selected, by changing the cut-off period, the explanatory variables, and also the estimation method (panel and individual time series models) We then compare models according to forecast results, forecast percentage errors, goodness of fit of the estimated regression, and significance level of the regression coefficients.
The general aggregate energy demand function our models are build on can be written as follows:

$$Y_{it} = f(RP_{it}, HDD_{it}\ , RGDP_{it}, POP_{it}, ST_{it}, t)$$

Where Y_{it} is the aggregated energy demand (electricity or gas), RP_{it} is the real price, HDD_{it} are the actual heating degree days, $RGDP_{it}$ is the real GDP, POP_{it} is population, ST_{it} is the stock of appliances, and t is the year.

Our general econometric model consists of a dependent variable and multiple explanatory variables. In this project the dependent variable is defined as the energy consumption of a single fuel (electricity or gas) divided by population (or employees in some cases). Based on the economic theory of energy demand, the following main factors were identified to influence energy consumption: energy prices, economic situation/development, and weather conditions. These factors are included as explanatory variables in all the models presented in this project. For some models, a time trend variable is added, which represents the change in equipment stock and/or other societal trends. The model is in log-log form (dependent and explanatory variables are expressed in logarithms) so that the coefficients can be directly interpreted as elasticities.

Energy prices are delivered for fuel categories on a half-yearly basis by Eurostat. From these half-yearly prices, annual average prices are calculated. Energy prices are transformed into real prices by correcting them with the individual GDP deflators for each country and period. In the case of Italy, electricity prices are missing for three consecutive years. However, prices including taxes are delivered for these years by Eurostat. The missing values are extrapolated by taking the average amount of taxes that add to the price of electricity and subtracting this value from the prices with taxes. Energy consumption is closely linked to the weather. The reason for this lies mainly in the fact that heating is the biggest part of residential gas consumption. In many countries, electrical heating is getting more popular compared to other heating methods. In that sense, cooler temperatures than normal also have an influence on electricity consumption. It is also very likely that people spend more time in the house using electric appliances in cold years and cooler climates. This also increases electricity consumption. The model accounts for climatic and weather conditions by including annual actual heating degree days for each country into the regression equation. Degree days are available for the period 1990 until 2009. The average value for 1980 until 2009 is then used for the year 2010.

Another important influencing factor of energy consumption is the economic situation. A general positive relation between economic growth and energy consumption can be observed although this correlation decreased slightly during the last years due to a more efficient and less energy intense economy. Nevertheless, the models show that the influence of economic growth on energy consumption is positive and statistically significant in most cases. The models account for economic growth and the economic situation by including GDP per capita or an industrial production index into the equation. The GDP is provided by Eurostat as real GDP per capita.

In line with our analysis of the available data and of the factors influencing energy consumption, we specify the following general econometric model:

$$\frac{\ln Y_{ijt}}{N_{ijt}} = \alpha_{ijt} + \beta_{HDD} lnHDD_{jt} + \beta_{RP} \ln RP_{ijt} + \beta_{RGDPPC} \ln RGDPPC_{ijt} + \beta_{ST} \ln ST_{ijt} + \beta_{DT} DT_{jt} + \varepsilon_{ijt}$$

where Y_{ijt} is aggregated energy consumption, N_{ijt} is population or number of employees, HDD_{jt} are the actual heating degree days, RP_{ijt} is the real price per kWh for electricity or per Gj for gas respectively, $RGDPPC_{ijt}$ is the real GDP per capita, ST_{ijt} is the stock of electrical appliances (e.g. refrigerators) DT_{jt} is a series of time dummy variables and ε_{ijt} is the disturbance term all for country j, year t and fuel market i[3]. As energy consumption and the regressors are in logarithms, the coefficients are directly interpretable as demand elasticity.

The general model is valid for all countries, sectors, single fuels and estimation methods. We estimate panel data models (with all 27 EU Member States and with only a small group of countries) and individual time series models. For the panel data models, we include fixed effects (FE) time and cross section dummy variables, whereas the cross section dummies are the individual intercepts, α_{ijt} and the time dummy variables are represented by DT_{jt} in the model specified above. For the individual time series models, one individual intercept and no time dummy variables are included in the model, as the time dummy variables capture the unobserved heterogeneity of individual countries.

Since the data availability is best for the residential electricity consumption models, we estimated a panel-27 model, two sub-panel models (one with four countries (DE, FR, IT, UK) and one with two countries (BG, RO), and individual time series models for Germany, France, Italy, and the United Kingdom. The reason why we estimated different models is to try out under which setting the model works best and we get the most precise saving estimates.

	Residential electricity
Panel 27 (y/pop, gdp)	x
Panel 27 (y/employees, value	

[3]There are four fuel markets analyzed in our project, hence i=1,2,3,4; residential electricity, tertiary electricity, residential gas, and tertiary gas.

added)	
Sub-panel (DE, FR, IT, UK)	x
Sub-panel (BG, RO)	x
Individual time series (3 variables)	x
Individual time series (4 variables, incl. fridge)	x

The energy demand models we estimated were then used as the basis for the energy consumption forecasts in order to determine the energy savings occurred in a specific country. We forecast for two cut-off periods (2006 and 2008), meaning the forecasting periods are two and four years respectively. The forecast consumption levels were then compared to the actual consumption levels, the difference between the two can be interpreted as the achieved energy savings under suitable assumptions. Generally the difference between actual consumption and forecasted consumption is the part that is not explained by our econometric model (the residual). In a regression the residual is usually the result of a combination of omitted variables, measurement error, misspecification of the model, and other random events. By including all relevant variables, choosing the correct function form (e.g. log-log as in our case), and minimizing measurement error by understanding the data, we are reducing the part of the difference/residual which is not due to a omitted variable. The variable which is missing (hence the omitted variable in our model) is clearly the level of energy efficiency policies in a given country. Hence, by controlling as good as possible for the other factors that make part of the residual, we can expect that the omitted variable, energy efficiency policy, takes up a large part of it. A significant part of the difference between actual and forecasted consumption can thus be attributed to the impact of energy efficiency policies. We cannot tell how large the part of the difference that is due to the energy efficiency policy variable is in terms of percentages but it can be shown that our models deliver good results and have a good overall fit. Nevertheless, we suggest to interpret the estimated savings as a general trend in savings rather than very precise estimations of actual savings.

3.2Estimation results

This chapter summarizes estimation outputs and results of the models estimated.[4]

The overall goal of the project is to quantify savings resulting from energy efficiency measures and policies. Important for our analysis is therefore the performance of the models in terms of forecasting preciseness, measured by the percentage forecast error[5]. This is a slightly different approach than usually undertaken in econometric studies, where the primary attention lies on the estimation outputs, i.e. sign and significance level of the coefficients and the goodness-of-fit measure (e.g. R^2). For the evaluation of the different models, we focus primarily on the preciseness of the forecasts. As we are interested in forecasting energy demand rather than explaining and interpreting the impact of each individual variable on energy demand, we place less focus on the individual coefficients of the regression estimation and place more emphasis on the preciseness of the forecasts.

Our analysis shows that the individual time series models produce – in most cases- better forecasting results than the panel models (by panel models we mean the panel-27 model with all 27 EU Member States and the smaller sub-panel models with 2-4 countries). The results from the individual time series models are generally more precise and more reliable than from the panel models. In some cases, however, panel models provide superior results for some countries. For instance, some sub-

[4]All estimation output tables, consumption forecast graphs, and savings' estimates and precision levels' tables can be found in the annex of the full report. The most relevant tables and graphs can be found at the end of this chapter.

[5] The percentage forecast error is calculated by dividing the standard error of the forecast by the forecasted consumption

panel models for a group of four countries (DE, FR, IT, UK) produce better results for some countries. In all models estimated some coefficients are statistically significant and carry the expected sign. [6]
As expected, the number of significant coefficients is generally a bit higher in the panel models. The differences in significance levels between panel models and individual time series models is most likely due to the number of observations. For the panel models, the number of observations is substantially higher than for the individual time series models.

In general, the estimation outputs are in line with our expectations concerning the sign of parameter coefficients. The results show that the price has a negative influence on consumption, although the price elasticity of energy demand is relatively inelastic. In some models, the values of the coefficient for the real price are also in the expected range, mostly close to -0.30 which is in line with usual estimates of price elasticity of electricity demand.

Actual heating degree days are significant and carry a positive sign in some cases, showing there is a positive correlation between heating degree days and energy consumption. However, our models also show that sometimes the influence of heating degree data is not as clear and important as may be expected, some of the coefficients are not significant and carry a negative sign. The coefficient for real GDP per capita is usually positive, showing that an increase in GDP will also increase energy consumption.

Apart from the three main explanatory variables (real price, real GDP per capita, and actual heating degree days) included in all models estimated, some models also include the stock of refrigerators. The coefficients for the stock of refrigerators, which is only included in the residential electricity consumption models, have the expected positive sign and are statistically significant in some cases (see Appendix), which indicates that the stock of refrigerators is important to be included in the models as time trend for the rate of use/change of appliances in households. Furthermore, it might be desirable to include a comparable variable also for gas consumption models.

Tab. 2: Comparison of regression coefficients of selected models for residential electricity consumption: Panel-27 LSDV (fixed effects) model vs individual time series models (OLS)

		Residential electricity consumption, three explanatory variables, cut-off period 2006							
		Panel 27 Model					Individual time series models		
Variables	EU-27	Coefficients	St. Err.	t-stat.	Variables	DE	Coefficients	St. Err.	t-stat.
Constant		-12,124860	0,677586	-17,894210	Constant		-15,052000	0,877522	-17,152830
RP		-0,296200	0,053339	-5,553187	RP		-0,063978	0,082963	-0,771168
RGDPPC		0,388337	0,060088	6,462799	RGDPPC		0,633204	0,067358	9,400638
HDD		0,145155	0,071626	2,026579	HDD		0,257335	0,034118	7,542399
						FR			
					Constant		-11,257080	3,759526	-2,994282
					RP		-0,594732	0,189174	-3,143831
					RGDPPC		0,254105	0,346695	0,732935
					HDD		0,150513	0,115271	1,305734
						IT			
					Constant		-10,659910	3,109759	-3,427889
					RP		-0,216080	0,103834	-2,081005
					RGDPPC		0,347446	0,284202	1,222530
					HDD		-0,006295	0,104989	-0,060013
						UK			
					Constant		-13,484400	1,274771	-10,577900
					RP		-0,028664	0,062834	-0,456190
					RGDPPC		0,525784	0,087932	2,575557
					HDD		-0,226376	0,089119	5,899765

Although the significance level of estimation outputs of our models is worth noting, the primary goal of the project is to produce precise forecasts of energy consumption and energy savings, therefore the

[6] The R^2 is generally in the expected range for the individual time series models. For the panel data models, the reported R^2 is not the correct one. To obtain the correct R^2 for a panel model, one has to calculate the within R^2 which adjusts for the fixed effects.

main focus should be on the forecasting results rather than on significance levels of individual coefficients. There exists a trade-off between estimation outputs that are statistically significant and the preciseness of the forecasts. Whereas the panel models generally produce a higher number of statistically significant coefficients, the individual time series models generally deliver more precise forecasts. The first result is – as already mentioned- due to the increased number of observations; the second result is due to the differences between countries. Although our panel models account for heterogeneity (observed and unobserved) between countries not all differences can be captured in the models. Therefore, individual models deliver more precise results for the specific countries. A prerequisite for estimating individual time series models is a sufficient number of observations. For France, Germany, Italy, and the United Kingdom the number of observations was sufficient to produce good forecasts whereas for Bulgaria and Romania we do not have enough observations and hence have to rely on the panel model estimates for these two countries.

3.3 Energy savings

For policy makers it is of crucial interest to know if the policies they implemented are delivering the desired results, in our case energy savings. During the last years, energy efficiency has become one of the main policy goals in energy policy in the EU. A series of EU-wide, national and also regional policies have been implemented. The models we estimated were built to forecast energy consumption and hence show the accumulated energy savings of the last years as a result of the policies implemented. Our results show that we can already see an impact of energy efficiency policies on energy consumption. The impact varies between sectors and fuels. The most significant effect of policies can be seen in the residential electricity sector where our models estimated energy savings for the majority of countries analysed. As explained in chapter 3.2, energy savings are calculated as the difference of actual and forecasted consumption. The difference between actual and forecasted consumption is largely driven by the omitted variable, energy efficiency policy, in our model. Although we cannot say how large the difference due to energy policy and how large the part of other factors influencing the residual is (as mentioned above the difference could in theory also be caused by measurement error, a wrong function form or temporary random events), we can show that our models have a general good fit, and deliver precise results with small forecasts errors. Hence, it is very likely that the difference between actual and forecasted consumption is mainly due to energy efficiency policies. The forecasts are produced based on the energy consumption models estimated. Since we estimated a series of different models (individual time series models and panel models) with different specifications (i.e. varying explanatory variables) our results in terms of estimated energy savings for the same countries differ between the models.

Our results show that the highest energy savings have been realized in residential electricity consumption showing that energy efficiency policies have already been successful there.
In line with our expectations, we find that for the four bigger EU countries (France, Germany, Italy, United Kingdom) our models estimated higher energy savings as for the two newer EU Member States, Bulgaria and Romania. This can be explained by the different implementation times of energy efficiency policies in the two groups of countries. Germany, France, Italy, and the United Kingdom started to implement policies to reduce energy consumption since the early 1990s whereas Bulgaria and Romania implemented most policies during recent years. Hence, results of these policies are not yet as visible as in the other four countries.

In the panel model for residential electricity consumption with all 27 EU Member States almost no energy savings are visible. The general observation is that actual consumption lies above forecasted consumption for the countries analysed only Italy and Germany achieved savings in this model. Contrary to that, the sub-panel models and individual time-series models show significant savings for most countries and periods analysed. The individual time series models estimated for France, Germany, Italy and the United Kingdom show savings in residential electricity consumption for all countries and periods except for France in the year 2010. Savings lie between 0.42% and 11.34% per year in these models. The graphs (Fig.2) show that actual consumption is flattening for the four countries whereas forecasted consumption follows a rising curve.

The most precise results are gained from the residential electricity consumption models, whereas the gas consumption models deliver less precise forecasts. This is to a great extent caused by an overall lower quality of the data for this sector compared to the data for residential electricity consumption. Furthermore, some variables included in the residential electricity consumption models (i.e. stock of electricity consuming appliances) are not are available for gas consumption such as the stock of energy consumption appliances.

The percentage errors of the forecast for the individual time series models are generally lower than for the panel models. Percentage errors for the individual time series models for residential electricity consumption with four regressors are between 0.63% and 4.61%. For residential gas consumption, our models delivered comparatively low forecasting errors lying between 2.56% and 6.91

In summary, we can say that policies are starting to have a visible effect on energy consumption, especially in the residential electricity sector, where our models show important energy savings for some countries. Furthermore, in Bulgaria and Romania, important energy efficiency potential could be realised. Until today, our models show no significant energy savings for these two countries. Concerning the preciseness of the forecasts, it can be said that individual time series models generally delivered better and more reliable results than panel models although there are some individual exceptions. Furthermore, it is important to note that the availability and quality of the datasets has a great influence on the models. Models generally produced better results where more data and data of better quality was available (as was the case for residential electricity consumption). Finally, we can say that our models perform generally well when being used for modelling electricity consumption and less well for modelling gas consumption.

Tab. 3: Forecasted consumption, energy savings, and percentage error of forecasts for the individual time series models for residential electricity consumption (regressors: RP, RGDPPC, HDD, ST), for DE, FR, IT, UK

Forecasted consumption & Energy savings		Cut-off period 2006			Cut-off period 2008		
		TWh Savings	% Savings	% SE Forecast	TWh Savings	% Savings	% SE Forecast
DE	2007	593,00	0,42%	0,63%			
	2008	2067,00	1,48%	0,94%			
	2009	3451,00	2,48%	0,55%	3.299	2,37%	0,60%
	2010	2144,00	1,51%	0,87%	1.286	0,91%	0,76%
FR	2007	5149,00	3,53%	2,69%			
	2008	5730,00	3,80%	2,77%			
	2009	4586,00	3,02%	3,57%	739	0,49%	3,41%
	2010	-7798,00	-4,80%	3,80%	-13.200	-8,12%	3,03%
IT	2007	2330,30	3,47%	1,36%			
	2008	4421,70	6,47%	1,53%			
	2009	7492,30	10,87%	2,54%	972	1,41%	3,50%
	2010	7914,90	11,38%	2,43%	1.655	2,38%	3,29%
UK	2007	3238,00	2,63%	2,93%			
	2008	8312,00	6,94%	3,97%			
	2009	9679,00	8,17%	4,29%	1.979	1,67%	3,62%
	2010	13567,00	11,43%	4,61%	6.030	5,08%	4,15%

Fig. 2: Forecasted and actual residential electricity consumption, individual time series models (regressors: RP, RGDPPC, HDD, ST), for DE, FR, IT, UK

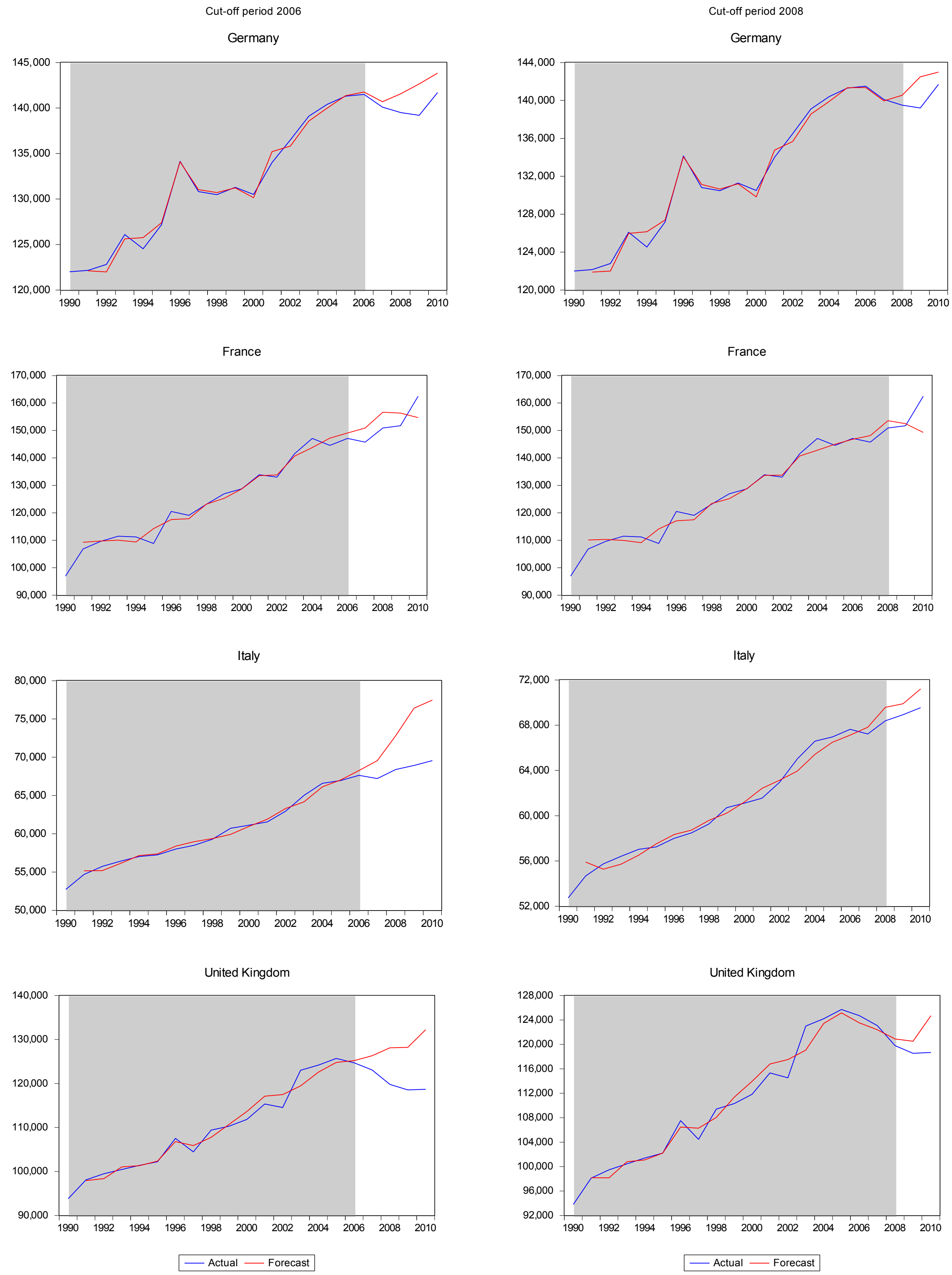
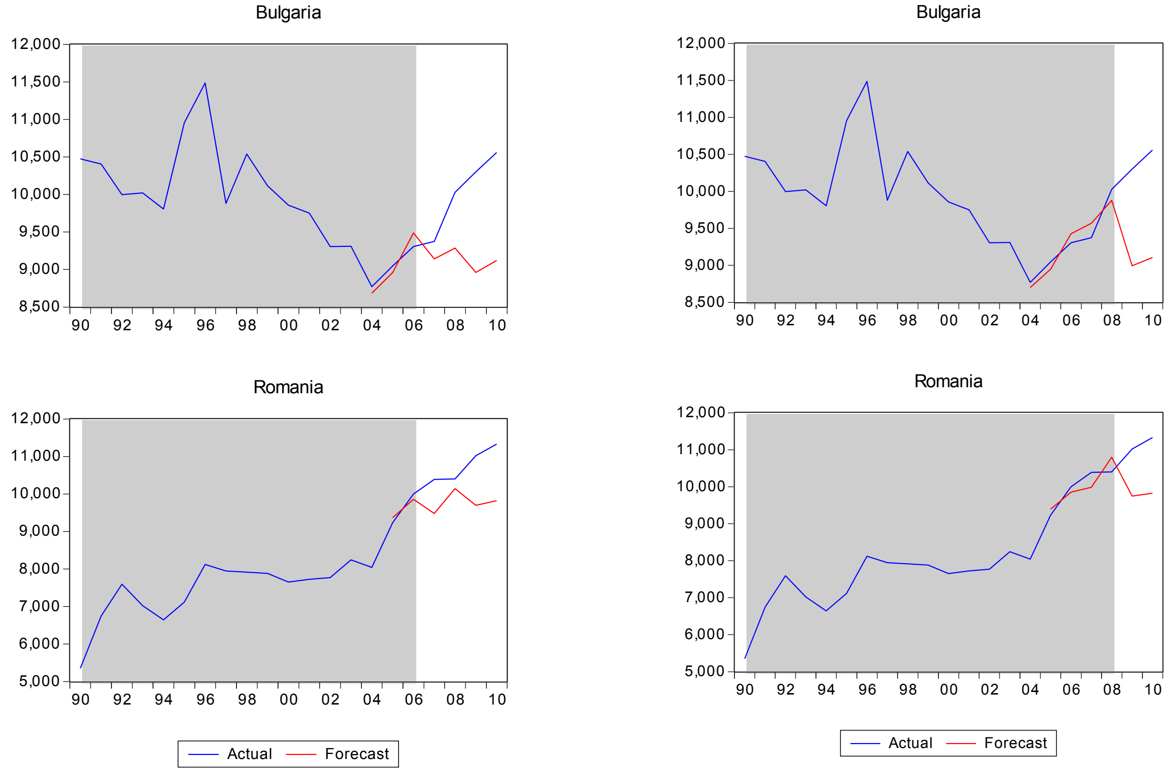


Fig. 3: Forecasted and actual residential electricity consumption, panel27 model (regressors: RP, RGDPPC, HDD), for BG and RO



4 Conclusions

Energy efficiency has become one of the main policy goals in energy policy in the European Union. In order to develop and implement new policies, it is of crucial importance for the policy maker to evaluate the impact of the policies. In this project we applied a general energy demand model to the residential sector to analyse electricity and gas consumption savings. Based on the econometric model, we estimated the respective energy savings for six selected countries. Our results show that energy efficiency policies are already starting to be successful and their impact on energy consumption is already visible in some sectors, as for instance in residential electricity consumption, where the majority of the analysed countries achieved important savings in consumption.
The project also showed that generally individual time series models deliver better forecasting results than panel models whereas panel models have a higher number of statistically significant coefficients.

This project has to been seen in the context of an ongoing study of energy consumption in the European Union. It builds a valuable basis for future research and points out opportunities and also difficulties for future research. The project shows that the models that have been used can deliver important and reliable results of energy savings estimates. However, it became also clear during the project work that the quality of the models' results depends to a large extent also on the quality and availability of the database. For future research projects, it will be of great importance to expand the now existing database with datasets that are not yet available now but will be maybe in the future. The datasets, estimation outputs, graphs and tables delivered by this project are a good basis for future research work.

Measuring Success in Mid-stream Programs: Design and Evaluation Recommendations from a TV Program

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Abstract

"Mid-stream" energy efficiency programs are gaining popularity in the United States because of the efficiency with which they can target a product's supply chain. These programs typically entail the formation of partnerships between major retail chains and program administrators, enabling them to reach a large proportion of the consumer market while maintaining just a few relationships.

Although funders and implementers have lauded the success of these programs in increasing adoption of efficient televisions, evaluations have not supported this perspective. Previous evaluations found that programs had little measurable influence on the complex and fast-changing television market. If an approach to evaluation cannot be found, major funders may withdraw their support, putting the future of mid-stream consumer electronics programs in the U.S. at risk.

Evaluators and program designers must meet three key challenges in order for mid-stream programs to continue, and succeed: 1) Create an evaluation approach for retailers and manufacturer participants; 2) Identify relevant, observable metrics for measuring a mid-stream program's success and establish an appropriate standard of proof for assessment of market influence; and 3) Agree on an approach to determine the market baseline, in other words, what would have happened, absent the program.

This paper proposes approaches to each of these challenges based on the authors' experience evaluating one of the largest and longest-running consumer electronics efficiency programs in the U.S. and discusses opportunities to employ the methodology from this study in evaluating energy efficiency policy and codes and standards efforts.

Introduction

"Mid-stream" energy efficiency programs take their name from the point, in a product's supply chain, they seek to influence – a middle ground between the product's manufacturers and component suppliers (the "upstream" players) and the end user. In the U.S., this middle ground is dominated by a handful of retailers. For example, four retailers together account for two-thirds of refrigerator sales (Sears, Lowe's, Home Depot, and Best Buy) and two retailers account for more than half of television sales (Best Buy and Wal-mart) [2, 3].

Mid-stream energy efficiency programs are gaining popularity in the United States because of the efficiency with which they can target a product's supply chain. Consolidation in the retail sector makes mid-stream programs particularly attractive because of their potential for operational efficiency, and with it a positive benefit/cost ratio. In these programs, administrators typically form partnerships with major retail chains, enabling them to reach a broad swath of the consumer market while maintaining just a few relationships. In addition, mid-stream programs facilitate access to top corporate decision-makers, direct influence over product assortment, and access to product sales data, impacts that end-user-focused programs may not as easily obtain.

These are a few of the advantages of mid-stream programs, to which there is also an important drawback: mid-stream programs are difficult to evaluate and in the U.S. there are few evaluation precedents. Below, we describe the evaluation of a TV energy efficiency program operated by the Northwest Energy Efficiency Alliance (NEEA), from 2009 to the present, in the Pacific Northwest region of the U.S. (the states of Oregon, Washington, Idaho, and Montana) [1].[1] The study can serve as an example to other evaluators of mid-stream programs, or energy policy or regulation, in how to meet three key challenges in evaluating these programs: 1) Creating a qualitative evaluation approach for retailers and manufacturer participants; 2) Identifying relevant, observable metrics for measuring a mid-stream program's success and establishing an appropriate standard of proof for qualitative assessment of market influence; and 3) Agreeing on an approach to determining the market baseline (what would have happened, absent the program) suitable to mid-stream programs. The evaluation described in this paper adds to the scant midstream program evaluation literature. Previous evaluations include a theory white paper and a baseline study conducted in advance of the launch of one of the first large midstream programs [4, 5]; an evaluation of NEEA's 2010 television program [3]; and a program "review" of a similar program in California in 2011 [8].

NEEA's TV Program

The Northwest Energy Efficiency Alliance (NEEA) is a non-profit organization that works to accelerate the innovation and adoption of energy-efficient products, services, and practices in the Pacific Northwest region of the U.S. In 2009, NEEA launched the Consumer Electronics Television Initiative (the program) with the goal of increasing the availability of energy efficient televisions at retail stores in its four-state region. As a mid-stream program, NEEA's TV program pays incentives to the retailers who sell the products, rather than the end users who buy them. The program theory stipulates payment of an incentive for each qualified product sale will lead to several outcomes, most important of which is that retailers will bring more qualified products into their TV assortments than they would absent the program.

The program's other activities include sustained engagement with retailers' corporate sustainability staff and in some cases TV buyers; the delivery of timely, detailed information about the program's energy specification to help retailers identify qualified models when making their assortment decisions; employment of retail store "detailers" who visit each participating store three to ten times per year to place point-of-purchase (POP) marketing materials on qualified televisions; the coordination of social media-driven marketing campaigns; and participation in the ENERGY STAR television specification development process to encourage the strictest possible energy consumption limits.

NEEA expected these activities to result in several outcomes of varying importance to the program's success. The most significant expected outcome, described above, was a shift in retailers' TV assortments to include a higher proportion of program-qualified products. Other expected outcomes included retailers taking actions to accelerate the sales of program-qualified TVs; retailers increasing their demand on TV manufacturers for program-qualified TVs; improvement in consumers and retail sales associates' ability to identify program-qualified TVs; and increasing stringency of the ENERGY STAR TV specification.

Although the program's other expected outcomes were given less emphasis by program managers and not considered by NEEA as critical to the program's success, the evaluation team found them useful in guiding the design of a study that would have enough breadth to uncover program influence, should it exist.

Evaluation Questions, Challenges, and the Study Design

The study design for the evaluation of NEEA's 2011 TV program was driven by NEEA's explicit research questions and the evaluation team's hypotheses about where the program's influence might be both material and observable. NEEA's several research questions fell into four key areas of inquiry, three of which provided evaluators with methodological challenges: What was the program's influence on television retailers, television manufacturers, and on increasing sales of qualified televisions?

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[1] The full study includes detailed findings and all data collection instruments. The study is the source of all data and quotes used in this paper, unless noted otherwise.

The study that resulted was multi-modal and included five distinct data collection activities, qualitative and quantitative analytical methods. Table 1 shows the evaluation activities, data sources, sample size, and the research areas addressed. Below we discuss the three biggest challenges to evaluating NEEA's TV program, and mid-stream programs in general.

Table 1. Data Collection Activities

Activity	Source of Data	Research Topics
Program Data Review	Salesforce.com database	Influence of program on retailer behavior Influence of program on ENERGY STAR specifications Characteristics of participating stores
	Reports submitted by store detailers	
	Public comments on proposed ENERGY STAR specifications	
	Comparison of findings with raw data from the previous evaluation	
In-depth Interviews	Program Staff	Influence of program on retailer behavior, including assortment decisions Influence of program on product design Influence of program on ENERGY STAR specifications
	Other TV Program Managers	
	EPA ENERGY STAR Staff	
	Retailer Corporate Staff	
	Manufacturers	
Store/Department Manager Surveys	Retail store and TV department managers	Influence of program at store level Store-level awareness of program
Retail Store Visits	"Mystery shopping" visits to participating stores	Store-level awareness and attitudes toward efficiency TV promotional activities
Sales Data Analysis	TV sales data submitted to online program incentives database	Characteristics of Northwest U.S. TV market Program influence on sales of qualified TVs

Challenge #1: Creating an evaluation approach for the supply chain

Although data collection needs vary based on the program design and research questions, efficiency programs targeting retailers and manufacturers will likely be attempting to influence both product assortment (the products on a retailers' shelves) and/or product design. As the NEEA evaluation showed, evaluating influence on supply chain partners like these is different, and more difficult, than measuring influence on end-users.

Retailers are the participants in the NEEA program and the program's ability to influence retailers' assortment decisions was perhaps the key factor in its success. More research questions focused on the program's expected impact on retailers than any other area. For example: How did retailer behavior change as a result of the program? How has NEEA's relationship with retailers changed as a result of the program? How have retailer attitudes toward efficiency changed at the corporate level and store management levels, as a result of the program?

In residential programs targeting end users, the decisions at the core of the evaluation are made by the product's purchaser, typically the one or two decision-makers in a household. In order to receive the incentive, participants usually provide the program with their names and contact information. Participants typically share a language and time zone with evaluators. In energy efficiency programs, participants rarely have any extenuating factors that make them unwilling to discuss their decision-making process (for example, privacy concerns are more common in medical studies). Even though some end-user participants may be unreachable or unwilling to speak to evaluators, there are usually a sufficient number of participants to constitute a representative sample, such that evaluators can apply both qualitative *and* quantitative evaluation methods to the data.

None of the characteristics of end user participants apply to the retailers and manufacturers who are the participants in mid-stream (or even up-stream) programs.

Evaluators may have limited access to the decision-makers. In mid-stream programs, the contacts with whom the program staff interact may not be the ultimate decision-makers who the program seeks to influence, and may be unavailable to evaluators. In the NEEA TV program, TV buyers were the ultimate assortment decision-makers but were usually unwilling to speak with evaluators, as were product managers and design decision-makers at major manufacturers. Among retailers, evaluators were only allowed to speak with buyers at one retail organization, even after repeated requests to different individuals. Questions submitted by email went unanswered. Further, most manufacturers' design staff are located in Asia; may not feel comfortable conversing in English, and were unwilling to respond to questions.

The decision-making process is a team effort. Unlike end-user purchase decisions made by householders, many people contribute to decisions made by organizations. In the NEEA TV evaluation, the number of individuals and corporate "teams" complicated the effort to understanding the program's influence.

The decision-making process is confidential. Retailers' assortment selection and manufacturers' product design processes are considered proprietary. As areas of competitive intelligence, interviewees were willing to speak only in generalities about their organization's processes and considerations. No one was willing to share evidence that would have allowed the evaluators to quantify or even just verify program influence, for example, a product selection algorithm or product matrix. As one retailer interviewee commented about his company's television selection algorithm, "Pursuit of confirmation of what that algorithm is would be futile. I work [there], and they won't even tell me. . . It's like asking for the secret combination for how to make Coca-Cola. They're just not going to tell you."

The small number of participants does not support quantitative evaluation methods. In a typical mid-stream program the participants, measured as business entities, will usually number in the single digits. If participants are taken as the unit of analysis, quantitative approaches to measuring influence are eliminated, leaving only qualitative or anecdotal methods.

Strategies for measuring influence on supply chain partners

The strategies the evaluators used to get around these barriers in evaluating NEEA's TV program may be useful to other evaluators. The team took the following steps:

Employ a multi-modal study design with consistency in research questions across modes. The study was designed for triangulation, and included several data sources *in addition* to in-depth interviews with the participants. This allowed for multiple data points on each research question and provided a balanced picture of the changes taking place in the market as a result of the program. As a result of a previous evaluation of the TV program, the evaluation team knew their go-to data collection activity for deeply qualitative information, the in-depth interview, would need to be supplemented by additional data sources. Interviews with retail store managers, “mystery shopping” visits to participating stores, a quantitative analysis of sales data, and a thorough review of program data all contributed to answering NEEA’s research objectives.

Use multiple informants at each organization. Business decisions may ultimately be made by a single individual, but many people contribute to them. Even though evaluators were not able to speak to the ultimate decision-makers, they did succeed in reaching multiple informants in varying positions within each retail organization, all of whom attempted to influence the TV buyers’ decisions. For example, at one major retailer, evaluators interviewed the sustainability lead, the utility coordinator, and a senior director focused on energy management. Evaluators had several conversations with the interviewees, some of which occurred in person at industry events.

Use program documentation to fill in the gaps. The implementer of the NEEA TV program used Salesforce.com to track email correspondence with the participants. Evaluators conducted a thorough review of this database and created a chronology of the program’s interactions with each participant organization.

Ask indirect questions and capture the nuance. In addition to asking a direct question like, “Do you have a sense of how often the fact that a TV is qualified for this program weighs into your decision to buy it?” evaluators also asked many indirect questions like, “What, if anything, would you have to stop doing if this program ended?” Another example of this approach was in the series of questions about the implementer and the information they provided. Evaluators chose not to use typical satisfaction questions and instead asked both about respondents’ familiarity (“Would you say that you feel well-informed about upcoming changes to the program’s specifications?”), usefulness (“How do you use the information from the program in your conversations with manufacturers?”) and suggestions for improvement (The implementer told us that they check in with you throughout the year. Is there anything they could do to better support you?”).

Hypothesize about what might have happened if the program achieved its desired influence, and test these hypotheses. This tactic influenced nearly every aspect of the data collection process, from interview questions to the inclusion of entire collection methods. Mystery shopping visits to participating stores and interviews with store managers, for example, were only included in the study in order to test these hypotheses but resulted in findings that were some of the most helpful to program managers in improving the program. For example, evaluators speculated that if the program influenced buying decisions, retail buyers would: demonstrate familiarity with the qualifying product criteria, have received them well in advance of their decision-making, and have discussed the specifications with manufacturers. Evaluators sought to document whether this was the case in their questions to retailers and manufacturers and close examination of the content and chronology of the program implementer’s correspondence. In another example, evaluators also theorized that if the program influenced retailers to work to increase sales of qualified products, corporate executives (the program’s primary contacts within the retail organizations) might have taken several possible actions, including: communicating program details to store managers and/or sales associates; providing incentives to store managers and/or sales associates for increased sales of qualified products; and acting to increase promotion of qualified products. Evaluators interviewed store managers and conducted “mystery shopping” visits to participating stores to document whether influence of this type was observable.

Challenge #2: Identifying observable, measurable metrics

Relevant success metrics are important for all social programs. For programs working with retailers and manufacturers, ensuring that the chosen metrics can be measured, given the realistic constraints of most evaluations, is an important selection criterion. In evaluating NEEA’s TV program we encountered four types of problems in the way the program documented its projected outputs (the program’s own work products) and outcomes (expected changes in the market). Below, we summarize the problems and recommendations for avoiding them. Table 2 provides metrics from the NEEA TV program that illustrate each of these problems and the evaluators’ recommended changes.

Outdated Metrics

Outdated program metrics prevent evaluators from gauging the true success of a program because they focus attention on factors that are no longer relevant. The key metric for the TV program’s interaction with its retailer participants was measuring the combined market share of participating retailers. This was an important metric during the program's first year or two, when the goal was to engage retailers in the program. But by the time of this evaluation the program had already achieved its goal of gaining 80% market share and that metric was no longer useful.

Recommendations

Evaluate the appropriateness of metrics annually. Revise outdated metrics to reflect the program's achievements and current goals. For example, a metric that gauges the extent of retailers' commitment to the program may be more relevant.

Imprecise Metrics

Imprecise metrics do harm to both the program and its evaluation. Precise metrics allow implementers to design activities that will incentivize their participants toward the program's own goals, and further allow implementers to make knowledgeable, thoughtful decisions about which activities to pursue and with what degree of effort. A key objective for the TV program was to influence retailers to "stock" and "promote" energy efficient TVs. Evaluators and program staff struggled to define precisely what was meant by "stocking" and how it should be measured. The retail industry uses "stock" to mean the number of units of a given model that are available for sale at a particular store and a specific time. The program used the word "stock" in the same way that the retail industry uses "assortment," meaning the variety of product models carried by each store. So what was to be evaluated? Stocking or assortment? In another example, program staff felt their program design de-emphasized the promotion metric and argued that they did not expect their activities to result in retailers' increased promotion of efficient TVs. Program documentation however gave equal weight to the program's influence on stocking and promotion.

Recommendations

Evaluate each metric to assess whether it is in fact a goal of the program, and of equal weight with other goals. Review the program logic model and/or other documentation for accuracy. Write a description of the activities that can be used to measure the metric, include what data need to be obtained and potential sources. Check with participants and/or industry literature to sure that the terminology used complies with typical industry conventions.

Un-measurable Metrics

Program staff and evaluators accustomed to end-user-focused programs may be surprised to find that some of the more straightforward elements in these evaluations are much harder to determine in a mid-stream program evaluation. Quantitative influence on retail assortment and manufacturer product design are examples of un-measurable metrics. In the NEEA TV evaluation, evaluators could not determine a way to quantify the program´s influence on either. Participants themselves were unable to render an estimate when asked directly in in-depth interviews and were not willing to give evaluators access to data that would allow quantitative assessment based on inputs to their decision-making process (or, may not have even possessed such data). Further, the data evaluators needed to measure changes to assortment or product design, which were difficult if not impossible to obtain. For example, lists of all TV models produced by every manufacturer in each model year and all of their features, energy use data, and the manufacturer's suggested retail price (MSRP).

Recommendation

Plan for evaluation during program design so that all metrics have an evaluation plan in place. Change or eliminate any metric for which an evaluation plan cannot be specified. Obtain access to data required for evaluation at program outset, or ideally when contracting with participants.

Inappropriate Metrics

It is possible for a program's success metrics to be up-to-date, precise, and measurable (i.e. meeting the criteria described above), but still not provide an accurate assessment of the program's progress. In cases like these we describe the metric as "inappropriate," but "irrelevant" or "misleading" may also be accurate. NEEA's metric, "Increase in the number of TVs that meet current ENERGY STAR specifications," is an excellent example. This metric is both precise and measurable, but irrelevant to measuring the program's influence as it is affected by changes to the ENERGY STAR TV specification and in TV technology.

Recommendation

Select metrics that are observable and verifiable. Ask whether a program's influence is likely to result in or lead to changes in the metric. If so, can the evaluation can distinguish the influence of the program from all other plausible causes that could influence this metric? If other potential drivers exist, program evaluators need to capture additional data in order to control for these alternatives.

Table 2. Example before/after comparison of success metrics for NEEA's TV program

Program Metric	Problem	Recommended Revision	Explanation
Market share of participating retailers exceeds 80% of NW TV sales	Outdated	Retailers and manufacturers contacted at correct times to influence decisions; ongoing needs addressed	Participation rate is an output of recruitment, and at this point is an assumption because it has already been completed. The recommended language reflects the output of the implementer's current activities.
TVs that consume less energy	Imprecise	Year-over-year decrease in annual TV unit energy consumption (UEC) at all sizes and price points	This is not an output of the program and cannot be measured with program data. Recommended wording increases clarity.
Retailers commit to stocking and promoting the most energy-efficient TVs	Imprecise and un-measurable	Retailers increase the proportion of qualified TVs in their assortment, and promote these TVs	This outcome is one of the most important in the program theory. However, the Initiative does not require retailers to make any explicit commitments, so as-worded it is not accurate and not measurable. "Stocking" refers to the number of units kept onsite at a retail store, an activity the Initiative is not aiming to influence. And the outcome should specify "qualified" TVs.
Increase in the number of TVs that meet current ENERGY STAR specifications	Inappropriate	Market data are sufficient to track initiative progress, support spec development and inform retailer discussions	This outcome is not a good indicator of Initiative progress and could indicate an overly lax ENERGY STAR specification or an increase in the total number of TV models produced. The desired outcome it reflects (decreasing TV UEC) is covered by "Year-over-year decrease in annual TV UEC at all sizes and price points"

Contextualizing program goals using market data

Once there are appropriate metrics for a mid-stream program, how does one define success? How much does the program need to increase sales? How much influence does the program need to have on decision-makers to be judged successful? While the answers will vary by program and metric, one rule that can be generalized to nearly all is to rely on the specific market context when setting the bar. The use of the market context in setting the program goals will provide program staff, funders, and policy-makers realistic expectations for potential program outcomes and guide evaluators in portraying the program's achievements as success or something less.

There have been two evaluations of NEEA's TV program, by two different evaluation firms. The first evaluator to study NEEA's TV program concluded the program had succeeded in establishing strong relationships with retailers but had not influenced their assortment decisions in any substantial way. The evaluator pointed to the fact that decision-makers stated the program was not one of the primary influences on their assortment decisions and were unable to quantify the influence of the program over their TV assortments. In support of these points, the evaluator paraphrased one major retailer interviewee as referring to the program generally as "a tie-breaker when deciding between two very similar models." Because retailers were unable to quantify how often the program served as a tie-breaking factor in their assortment decisions, this information could not be used to measure the program's impact.

We, the authors of the second and more recent evaluation of NEEA's TV program, reached a very different conclusion based on much the same evidence from retailers, but with one major difference: we contextualized the findings based on what we had learned about the retailer's *milieu*. Like the first evaluation, decision makers told us the fact that although they did consider whether a particular television model qualified for a program incentive, this was never the primary factor in their decision to include the product in their assortment. But when we asked retailers to explain the broader context of the assortment decision, we learned why energy efficiency and NEEA's TV program were not of the utmost consideration. Other product characteristics, including supply chain security, product features, value to the customer, and negotiations with manufacturers take priority. One interviewee said balancing all of the considerations is like putting together a jigsaw puzzle with "ten or twelve really big pieces." In this context, it becomes obvious that energy efficiency will never trump factors like supply chain security and retailers' need to minimize the potential for disruptions to product availability. Nor will retailers bring products into the assortment if doing so jeopardizes their relationship with manufacturers, who provide retailers with "market development funds" as an incentive for retailers to assort particular models or a particular number of models, or promote their products in certain ways.

As a result of contextualizing the program goal of influencing retail assortment decision-making within the retailers' operating environment, we came to the conclusion that the Initiative had succeeded in influencing retailers to consider its qualification criteria during their assortment decision-making. A no small task considering the number of influences with which the program was competing. We further judged that because the assortment decision-making process is complex and critically important to the retailers' financial success, the program's potential for impact on this area of decision-making was extremely limited.

Challenge #3: Setting the baseline

In the U.S., energy efficiency programs use a variety of methods for calculating a program's impact on energy savings. The method used by market transformation programs and most mid-stream programs may be described as a "baseline" method because it attempts to determine what would have happened absent the program. Baselines are commonly set in one of two ways.

A *hypothetical baseline* is created by evaluators or program staff based on a series of assumptions about the market, ideally grounded in market data. NEEA uses the hypothetical baseline approach to establish energy savings for its programs. Key inputs include the estimated "take-off" year of the incented product, absent the program, and the number of years required to reach full market penetration potential.

A *measured baseline* is composed of data on program metrics from non-program areas. In the last few years, "non-program areas" have been defined as geographic areas outside the program's service territory. The evaluation of NEEA's TV program took a similarly quantitative, but very different approach to creating a measured baseline. The evaluation applied a quasi-experimental design methodology to estimate program impact on TV sales. The method compares findings from treatment and control groups and is similar to quantitative approaches used in research projects in psychology or the medical sciences. The use of statistical analysis, following a quasi-experimental design approach, bears much potential for energy efficiency program evaluation and may be especially fruitful when program interventions can be designed in cooperation with evaluators, thus allowing an even broader range of analysis.

Using sales data to set a measured baseline for mid-stream programs

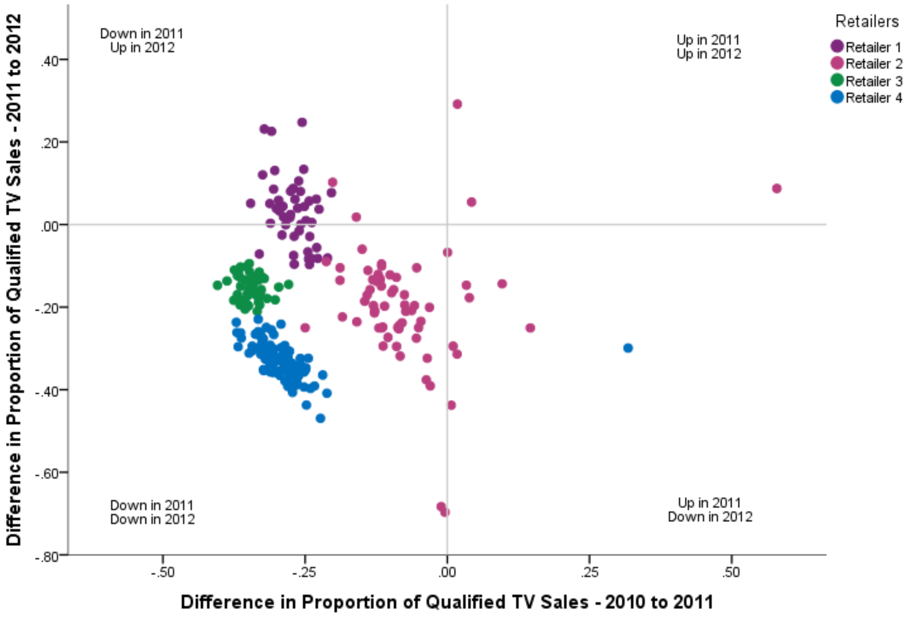
One benefit of mid-stream programs is access to detailed unit sales data provided by the participating retailers. These data can be obtained in other ways, for example purchased from a third-party like NPD or GfK, or tabulated based on submitted rebates (in an end-user focused program). Retailer-sourced data has several advantages, however. Retailer data includes identifying information for each unit sold, like retail chain and store, that is absent from aggregated third-party data and necessary for statistical analysis of program influence. Retailer-sourced data may also include fields of use to program managers and evaluators, like the presence or absence of efficiency features. And retailer-sourced data, unlike unit sales data derived from end users' rebate submissions, has the potential to include "full category" data, meaning all unit sales and not merely qualified unit sales.

There were several challenges in using sales data to evaluate the impact of this mid-stream program, and which other evaluators will likely encounter:

National retailers centralized decision-making and consistent store-level execution, combined with only limited regional program activities, resulted in the lack of an adequate control group. NEEA's TV program focused on building relationships with national retail chains and conducted limited regional activities, other than field staff visits to stores to place program point-of-purchase materials. Because retail chains determine product assortment nationally, with little regional variation, the program's influence on assortment affected the energy efficiency of televisions available nationally, not just in NEEA territory. This spillover effect benefits consumers but was detrimental to evaluators' ability to measure impact. In addition, the evaluation provided new evidence of the consistency in execution among stores in retail chains, further supporting the importance of regional, store-level activities to the quantitative evaluation effort. Sales data showed the proportion of qualified televisions sold by same-chain stores changed in similar ways, either increasing or decreasing from year to year, from 2010 to 2012. Figure 1 provides a visual representation of these changes, with each point representing a single store and the color denoting the store's chain. Points of the same color cluster together with few outliers, showing that chain stores perform similarly to one another and thus that execution is consistent within a chain. There is almost no overlap among the color/chain clusters, showing that the four major chains perform differently from one another. Results show that the majority of stores decreased sales of qualified televisions from 2010 to 2011 (all stores in the left two quadrants in

Figure 1). The high proportion of qualified televisions sold in 2010 (81%) partially explains the decrease in sales for the bulk of stores in these two quadrants. As the specifications became more stringent in 2011 and 2012, sales of qualified televisions decreased. In contrast to the other three retailers, most of Retailer 1 stores increased sales of qualified televisions in 2012. The clustering of same-chain stores suggests good store-level execution of a chain's planogram. This, in turn, reinforces that the program influences national retailer behavior, limiting the measurability of program impact regionally without region-specific activities.

Figure 1: Differences in the Proportion of Qualified Television Sales by Retailer, 2010-2012



Insufficient data to define a control group. In order to create a control group, the team required two types of information: sales data from non-participating stores in areas without TV energy efficiency programs, and detailed store characteristics for all stores, to support the use of propensity score analysis (a statistical technique for making comparisons between treatment and control groups). None of the retailer participants supplied store characteristics and only retailer supplied sales data from non-participating stores. Although the retailer did provide full category data, they were at the year and state levels (for example, total 2011 sales in Florida), limiting the potential for statistical analysis to a simple comparison of the average proportion of qualified televisions sold annually. This comparison lacked face validity because evaluators could not control for previous impact factors on sales, such as: regional promotional activities, seasonal differences, and store-level characteristics.

Varying levels of data quality, with two of the biggest retailers providing low-quality data. Evaluators needed full category sales data in daily or at least weekly intervals. Out of the four biggest retailers, only two provided quality data. One retailer provided only qualified product sales, preventing the team from including this retailer in any of their analysis. A second retailer provided data in monthly rather than daily increments.

These challenges and findings, from the qualitative portion of the evaluation, led the team to execute only one of its four intended approaches. All of them have the potential to be employed to evaluate other mid-stream programs, should the program design and data collection support them. They are:

Compare periods before and after a change in program criteria. Evaluators hypothesized that if the program was influencing retailers to boost sales of qualified TV models, the proportion of sales of qualified units would be visible around periods in which the program criteria changed. For example, a decrease in sales of televisions that no longer qualified for an incentive. Two factors curtailed this approach. First, the program's sales data lacked information on non-energy related television features like unit sale price that could confound this analysis. Interviews revealed a second confounding factor: retailers assort low-priced televisions specifically for the holiday period, the same period in which the program criteria changed. Further, field staff data and store manager interviews showed store-level staff lacked direction from corporate, awareness of the program and its qualification criteria, and did not conduct the type of promotion necessary to support the underlying hypothesis.

Compare similar participating and non-participating stores. This approach requires detailed characteristics for all stores in order to match participating and non-participating stores. The approach also requires sales data from non-participating stores at the same level of detail as those received from participating stores. As noted above, the data required to make this comparison were lacking, as were the program design elements required to show variation.

Compare major national chains and small chain and non-chain stores. The small data sample size and the lack of sales dates prevented this analysis. Although some minor and non-chain stores provided full category data, many provided only partial year data for 2011, disqualifying many potential statistical comparisons. Additionally, buying groups typically provided the sales data for minor and non-chain stores, rather than the stores themselves. Thus the date-of-sale included with each unit was the date when unit shipped from the buying group to the store; not the date-of-sale to the customer. Lacking a probable estimate for the length of turnover for these units, evaluators could not accurately compare sales between major chain and non-major chain stores.

Quantitatively assess influence of promotional activities. This approach holds perhaps the greatest potential for quantitatively evaluating mid-stream program impact. It requires implementing program activities following an experimental or quasi-experimental design approach. It demands either cooperation between program staff and evaluators or, as was the case in the NEEA evaluation, a spot of luck. One of the participating retailers aired a 15-second promotional video on in-store video walls at one of the major retailers. The data were sufficient to support analysis because the retailer provided high-quality data and the video aired in a one-month-on, one-month-off pattern throughout nearly the entire calendar year, providing treatment and control periods.

Case study: Findings from the statistical analysis of the NEEA TV program's sales data

The NEEA TV program expected to increase sales of TVs meeting the program qualifications in NEEA territory. In two cases, statistical analysis showed an increase in sales of qualified televisions resulting from the program's activities. A program-produced video, aired at all stores in one major chain, increased sales of top-tier televisions (televisions qualified at the highest energy efficiency level incented by the program). Across all retailers, an increase in the proportion of qualified televisions in a retailers' assortment increased the proportion of sales of qualified televisions.

Statistical analysis showed evidence that a promotional effort Initiative increased sales of top-tier televisions[2]. One participating retailer played an Initiative-produced video on in-store video walls in its stores during alternating months of 2011 (February, April, June, August, October, and November). Top-tier TV sales increased 3% in months when the video played, compared to months when it did not (11% of total sales compared to 8%)[3].

A second program impact demonstrated, by analysis of sales data, there is direct relationship between television assortment and sales, with a 1% increase in assortment leading to a 1.3% increase in sales of qualified products[4].

Conclusions and Recommendations for Designing and Evaluating Mid-stream Programs

The study yielded many recommendations specific to NEEA's TV program, but with broad applicability to other mid-stream programs.

Mid-stream programs are most effective when a set of shared program requirements are incented in cooperation by several funders. Mid-stream interviewees agreed that achieving a critical mass of program sponsors is key to earning their attention and participation. When evaluating a program with several sponsors, evaluators need to balance the role of their client with the impact of the sponsorship

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[2] Top-tier TVs in 2011 were ENERGY STAR 5 + 20% televisions.

[3] A repeated measures t-test ($t(49)=-8.1$, $p<.0001$) was used to compare the averaged proportion of sales of top-tier TVs, by store, in months when the video did and did not play. Sales in November and December were excluded because the video played in both months and did not follow the alternating-month pattern found during the rest of the year.

[4] A random effects model showed a significant effect of assortment on the proportion of qualified TVs sold.

group as a whole. Local or regional activities, discussed below, can help identify the impacts of a single funders' efforts.

Participants' contracts should specify, and incentive structures should support, the activities or goals the program desires. The way in which a program contracts with its mid-stream partners, significantly impacts program results. Programs have many options in structuring incentive payments (for example, paying per-unit vs. for meeting sales targets) and as the study showed, programs would be wise to make explicit the expected commitments from its partners.

Programs need to plan ahead at least as far as their supply chain partners. Retailers and manufacturers plan much further ahead than typical efficiency programs, and the design-sales cycle times vary greatly depending on the product. The market timing should be taken into account when programs plan releases of and updates to qualification criteria, plan promotional campaigns, and enter into contracts.

Regional or local activities are important to support impact evaluation, if designed following an experimental or quasi-experimental design approach. Even though mid-stream programs recognize operational efficiencies by focusing on retailers' corporate-level staff, activities at the store level are necessary to further increase product sales and support quantitative evaluation. Even with today's national markets, evaluators can still measure what happens locally, when data collection and intervention design are sufficient.

Evaluators need to look at the entire supply chain, even if the program's activities are more limited. In this study, actionable findings resulted from looking at all levels of the TV supply chain, from manufacturers to sales associates, even though the program's activities focused on interacting with retailers' corporate staff.

Data collection is an important part of mid-stream programs. Sales data collection is key, especially for tracking program impact. Sales data should be "full category" and include all product characteristics, including sales price or MSRP, and sale data, including store and date. Store characteristics are also important, including store location, format, size, sales area, age, number of local competitors, proximity to local competition, volume code, shrink, and surrounding demographics. Field staff, too, should track multiple data points during each store visit, including identifying store data, visit date, time in store, version of POP materials, number of qualified products on display, number of qualified products found unlabeled and incorrectly labeled, number of sales associates trained, and any positive or negative feedback received from store staff or customers. It is also important for program managers to track their correspondence with mid-stream participants. Salesforce.com served as an effective tool for the NEEA TV program, although it is incumbent on the program staff to be conscientious in uploading contact records, and for evaluators to provide program staff several reminders to make those uploads before beginning their evaluation.

Like all energy efficiency programs, a detailed logic model and up-to-date progress indicators are vital to evaluation. Program managers know more about the markets in which they're acting and the characteristics of their mid-stream partners than evaluators. Program documentation provides evaluators a roadmap to the program's current state of knowledge and helps focus the evaluation, resulting in study findings that will be relevant and actionable. Accurate documentation is also a guide for program managers, who can use it to prioritize their "asks" when negotiating with retailers.

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THE SUPPLY SIDE MATTERS: ESTIMATING THE IMPACT OF A RESIDENTIAL LIGHTING PROGRAM USING SALES DATA

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Abstract

Compact fluorescent lamps and light emitting diodes use about one-quarter as much energy as incandescent lamps with similar lumen outputs. Although they have higher initial costs than do incandescent lamps, compact fluorescent lamps and light emitting diodes last from ten to twenty times longer than incandescent lamps. This report provides an evaluation of the energy and peak impacts of the BC Hydro Energy Star Lighting Program, which is a multi-year energy acquisition and market transformation initiative that encourages its customers to use energy-efficient lighting, with a focus on compact fluorescent lamps (CFLs), light emitting diodes (LEDs), Energy Star fixtures and LED fixtures. The BC Hydro Energy Star Lighting Program has been successful in increasing product availability, product awareness, product affordability and product acceptability for energy efficient lighting. A significant degree of market transformation has occurred with respect to replacement of traditional incandescent lamps with spiral CFLs. The program reported energy savings for F2012 of 16.2 GWh per year compared to evaluated savings of 28.7 GWh per year. The difference between the evaluated and the reported savings is primarily due to the evaluated impact of spillover.

Introduction

Compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) use about one-quarter as much energy as incandescent lamps with similar lumen outputs. Although they have higher initial costs than do incandescent lamps, compact fluorescent lamps and light emitting diodes last from ten to twenty times longer than incandescent lamps. To earn the Energy Star label, manufacturers must certify that the product meets the energy efficiency criteria jointly set by Natural Resources Canada, the US Environmental Protection Agency, and the US Department of Energy. When products are certified to meet these energy efficiency standards, the manufacturers may place the Energy Star label on their lighting products. As technology advances and more energy-efficient lighting products are available in the marketplace, Energy Star reviews the guidelines for the lighting category and strengthens them as necessary to ensure that generally only the top 25% of lighting products in terms of energy efficiency can earn the Energy Star label.

The BC Hydro Energy Star Lighting Program is a multi-year energy acquisition and market transformation initiative that encourages its customers to use energy-efficient lighting, with a focus on CFLs, LEDs, Energy Star fixtures and LED fixtures. The objectives of the program include: (1) sustain and increase a greater market share in advance of regulations for more efficient lighting; (2) promote efficient lighting products not covered by regulations and newer products such as LEDs; (3) promote and increase awareness and drive customers to retailers to purchase efficient products; and (4) provide residents province-wide with an accessible and simple lighting program.

This report provides an evaluation of the impacts and effects of BC Hydro’s Energy Star Lighting Program. A quasi-experiment involving non-equivalent group comparisons was employed to assess supply and demand side impacts, and to estimate energy and peak savings. A number of methods have been proposed to estimate free riders and spillover including purchaser self-report surveys, trade ally surveys, quasi-experimental designs with a comparison group, and discrete choice modelling.

Literature Review

In many jurisdictions, residential lighting programs represent a significant share of electricity demand side management (DSM) savings. To date, most of these savings have come from the promotion of purchase and installation of standard twister or spiral CFLs. As a significant degree of market transformation has been achieved with standard CFLs replacing incandescent lamps, a number of utilities and other DSM implementing agencies have reduced or eliminated incentives for standard CFLs, and they have instead provided support for purchase and installation of “specialty” CFLs including reflectors, A-lamps, globes and dimmable lamps; Energy Star lighting fixtures; and LEDs. Residential lighting programs have emphasized four main mechanisms.

(1) Upstream Buy-Down. Upstream buy-downs involve retail price reductions where incentives are provided to manufactures which then provide a mark down to the retailer, who provides a reduced price to the consumer at the time of purchase.

(2) Direct Installation. Direct installation typically involves the installation of CFLs at the time of a residential audit.

(3) Downstream Buy-Down. Downstream buy-downs typically involve point-of-sale or mail-in coupons for consumers to obtain the product at a discounted price.

(4) Give Away. Give away typically involves provision of free CFLs at promotional events or through the mail.

A large number of studies have evaluated the impacts of residential lighting programs on energy consumption. Almost all studies use some form of the following algorithms to estimate energy savings and, less frequently, peak demand savings. Key parameters in these algorithms are the difference in average watts between the base and the efficient technology (delta watts, ΔW), annual hours of use, the peak coincidence rate, the installation rate net of replacements which is often called the in-service rate (“Install”), the free rider rate (FR), the spillover rate (SO), the cross effects rate (CE) which is often called the cooling and heating interactive effect, and the number of rebated measures. For first-year energy savings, the basic algorithm is:

$\Delta kWh = \Delta W \cdot Hours \cdot Install \cdot (1 - FR + SO) \cdot (1 - CE) \cdot$ no. of measures.

For peak demand savings, the basic algorithm is:

$\Delta MW = \Delta W \cdot Coincidence \cdot Install \cdot (1 - FR + SO) \cdot (1 - CE) \cdot$ no. of measures.

An extensive literature review was undertaken to understand the values of these various parameters calculated in recent studies. The data bases examined included the Social Science Research Network, the Consortium for Energy Efficiency, California Measurement Advisory Council (CALMAC) International Energy Program Evaluation Conference (IEPEC) Proceedings and Scopus. In a number of cases, only some of the parameters were provided, but the others could be derived from available information.

Some observations on these studies include the following.

Delta Watts. Delta watts refers to the difference between the (average) wattage of the efficient lighting measure and the (average) wattage of the baseline measure. The delta watts vary from 33.3 watts (PG&E, CFL globes) to 53.3 watts (Focus on Energy Wisconsin, CFL). Recent studies have used a variety of approaches to estimate delta watts. The self-report method uses customer survey information to determine the wattage that was used before and after the lamp or fixture change out. The in-home inspection approach uses program implementation contractors to determine the pre-efficient measure wattage in similar fixtures. The multiplier approach assumes that the baseline wattage is an assumed multiple (between three and four) of the efficient wattage. The manufacturer rating approach uses replacement wattage information on the lamp packaging.

Daily Hours of Use. Daily hours of use refers to the estimated hours of use of the efficient lighting product. The hours of use vary from 1.30 hours per day (SDG&E, CFL globes) to 3.20 hours per day (NYSERDA, CFL). Hours of use is affected by a number of factors including demographics, attitudes towards energy use and energy efficiency, dwelling type and age, saturation rate of lamps and fixtures, location and application of the lamps, electricity prices and hours of sunshine. Hours of use is estimated from on-site metered data, with some key considerations for the metering protocols including the type of loggers used (current sensing vs. light sensing), the length of the metering period (short periods with statistical modelling versus twelve months to produce annual load shapes), additional data collected on site (such as a full socket inventory) and data integrity.

Peak Coincidence. Peak coincidence refers to the share of lamps which are on during the peak demand period. The peak coincidence vary from 0.032 (SDG&E, reflector) to 0.22 (Markdown and Buydown, New England). Peak coincidence is also affected by a number of factors including demographics, attitudes towards energy use and energy efficiency, dwelling type and age, saturation rate of lamps and fixtures, location and application of the lamps, electricity prices and hours of sunshine. Again, peak coincidence is estimated from on-site metered data, with some key considerations for the metering protocols including the type of loggers used (current sensing or light sensing), the length of the metering period, additional data collected on site.

Installation Rate. The installation rate or in-service rate represents the percentage of incented lighting products which are ultimately installed by the program participant. The installation rates vary from 0.67 (PG&E, CFL globes) to 0.83 (New Jersey Clean Energy, CFL). Installation rates are affected by a number of factors including whether the efficient technology is replacing an inefficient technology, whether the customer is responsible for purchase and/or installation, whether products are purchased in multi-packs, the type of lamp and especially the length of life of the lamp being replaced, and the discounted price.

One – Free Riders + Cross Effects. Free riders refer to customers who received an incentive to purchase an energy efficient lamp or fixture, but would have purchased the energy efficient product at the same time without the incentive. Spillover refers to customers who purchased an additional energy efficient lamp or fixture without an incentive, but would not have done so at the same time in the absence of the program.The one minus free rider plus cross effects vary from 0.36 (NYSERDA, CFL) to 1.00 (Markdown and Buydown, New England and New Hampshire Home Performance, CFL). A number of methods have been proposed to estimate free riders and spillover including purchaser self-report surveys, trade ally surveys, quasi-experimental designs with a comparison group, and discrete choice modelling.

One – Cross Effects. Cross effects or interactive effects refer to the waste heat given off by lamps which affects heating, cooling and ventilation energy requirements. Only one utility, EmPOWER Maryland, reported a one minus cross effects value which was 1.06. For the non-reporting utilities, it was assumed that the one minus cross effects value was 1.0. Cross effects are affected by a number of factors including space conditioning mode, climate zone, dwelling characteristics, electricity and natural gas prices and attitudes towards energy use and energy conservation.

Method

The basic design of this evaluation study was a quasi-experiment with a non-equivalent comparison group. For the evaluation, there were five main activities: (1) conduct a program review; (2) undertake a supply-side assessment; (3) undertake a demand-side assessment; (4) measure hours of use and peak demand; and (5) estimate energy and peak savings. This study used multiple lines of evidence, which are summarized as follows:

Program Review. To undertake the program review, we reviewed program documents, interviewed BC Hydro staff, and built a program logic model.

Supply-side Assessment. To conduct the supply-side assessment, we tabulated and examined results of annual in-store surveys of lighting stocking behaviour at representative samples of retail establishments. The surveys have about 40 participants per year.

Demand-side Assessment. To conduct the demand-side assessment, we tabulated and examined results of the 2011 residential lighting surveys. The treatment group survey (British Columbia survey) had 601 respondents and the comparison group survey (North and South Dakota) also had 601 respondents. We also used information from the Residential End Use Surveys conducted since 1997 to build econometric demand models for energy efficient lamps. We also received, aggregated and analyzed limited sales data for the time frames before, during and after the marketing campaign.

Hours of Use and Peak Coincidence. To measure hours of use and peak coincident demand, we conducted in-home monitoring of 333 lighting fixtures in some 50 single family dwellings, with each fixture monitored for a minimum of twelve months.

Energy and Peak Savings. To estimate energy and peak impacts, we used detailed engineering algorithms which were informed by the data from the supply-side assessment.

Results

Program Review. From a program logic perspective, there were three main program activities: retailer education, product rebates and consumer education.

(1) BC Hydro Power Smart has provided retailer education for the residential lighting market since the inception of the program. Retailer education is a key component of the current Energy Star Lighting program, and retailer education has both on-site and on-line components.

(2) Product rebates are aimed at creating customer interest in energy efficient lighting and reducing first costs. The Lighting Campaign Spring 2011 included in store instant discounts on selected lighting products from March 1 to April 30, 2011, while the Lighting Campaign Fall 2011 included in store instant discounts on selected lighting products from October 1 to November 30, 2011.

(3) Consumer education is aimed at creating customer awareness, knowledge and purchase intent for energy efficiency lighting products, and the lighting campaigns included radio, print, television and point of purchase materials.

A key aspect of a program review is an assessment of the program rationale, in other words, does the program make sense? Program rationale can be assessed in a variety of ways, but the most straight forward way is to build a program logic model. A program logic model divides a program into its main activities, and then examines the logic chain of inputs, outputs, purpose and goal for each activity. The following table provides a program logic model and describes key assumptions which must be met for the program to be effective. The program rationale was examined using this program logic model, which was developed from interviews with staff, a documents review and a literature review. This review and analysis confirmed that the basic program logic was valid. There were strong linkages among inputs, outputs, purposes and goal statements. Indicators for key components of the logic model were clear, well defined and measurable.

Table 1. Program Logic Model

	Retailer education	**Product rebates**	**Consumer education**	**Assumptions**
Inputs	Retailer staff training conducted	Power Smart and manufacturer rebates in place	Advertising, promotions and point of purchase material provided	Suitable inventory available in stores
Outputs	Increased sales person knowledge of energy efficiency	Reduce first cost of energy efficient lighting products	Increased customer knowledge and awareness of energy efficiency	Energy efficient lighting meets customers' lighting requirements
Purpose	Increased sales of energy efficient lamps by 679,000 units and energy efficient fixtures by 186,000 units by fiscal 2014			Rebound is negligible
Goal	Save 41 GWh of energy per year by fiscal 2014 at program cost of 414.9 million			-

Supply-side Assessment. The main supply side analysis was an examination of trends over the most recent three years using shelf stock information. Table 2 shows trends in shelf stock shares for standard base lamps. For the three years for which we have data, the shelf stock shares by lamp type are constant, with the share of energy efficient lamps (CFLs and LEDs) at 28%. Note that halogen share was available only for the 2011 survey, so it was assumed that this share was constant, which is consistent with evidence from recent Residential End Use Surveys on installed lamp shares.[1]

Table 2. Shelf Stock Shares by Product

Product	2009	2010	2011
		Lamps	
Incandescent lamps	61	61	60
CFL	23	24	24
LED	4	3	4
Halogen	12	12	12
		Fixtures	
Energy Star fixtures	6	8	7
Other fixtures	94	92	93

Table 3 shows trends in prices for lamps. From 2009 to 2010, incandescent lamps have fallen in price, and most types of CFLs have increased in price. There is not yet enough information to make a conclusion about LED lamp or halogen lamp price trends.

Table 3. Prices for Selected Products (dollars)

Product	2009	2010	2011
		Lamps	
Incandescent 40 W	1.14	0.80	0.91
Incandescent 60W	1.20	0.85	1.10
Spiral CFL	4.21	4.29	4.58
Globe CFL	7.42	7.53	8.55
A19 LED	-	24.63	24.34
PAR LED	-	27.27	29.13
		Fixtures	
ES ceiling fan	118.78	118.51	155.73
ES ceiling fixture	33.47	32.44	39.66
ES floor lamp	73.51	55.69	50.79
ES table lamps	37.70	22.96	22.36

Demand-side Assessment. Survey respondents were asked about whether or not they were aware of various lighting products, and Table 4 shows the survey results for lighting product awareness. Differences which are significant at the 10%, 5% or 1% level are indicated by one, two or three asterisks respectively. BC survey respondents show a higher level of awareness than Dakota survey respondents for all four lamp categories, and these differences are statistically significant for every lamp product category except incandescent lamps. Dakota survey respondents show a higher level of awareness than BC survey respondents for both fixture categories, and these differences are both statistically significant.

[1] Note, as of January 2011 British Columbia prohibits retailers from ordering 100 and 75 watt incandescent lamps. These actions do not affect the data in this report, but will be apparent in the next round of data collection.

Table 4. Product Awareness (%)

	BC	Dakotas	Difference	Z-test
Incandescent	97.4	97.0	0.4	0.35
CFL	94.5	91.8	2.7*	1.83
LED	71.7	63.7	8.0***	2.96
Halogen	84.3	77.7	6.6***	2.94
Energy Star fixture	28.8	35.6	-6.8***	-2.53
LED fixture	43.4	50.6	-7.2***	-2.48

One, two and three asterisks mean that the coefficient is statistically significant at the 10%, 5% or 1% level respectively.

Survey respondents were asked whether or not they had purchased various lighting products, and Table 5 shows the survey results for lighting product purchases. BC survey respondents show a higher level of purchase than Dakota survey respondents for three of the six product categories, and these differences are statistically significant. Dakota survey respondents show a higher level of purchase than BC survey respondents for basic CFLs and specialty CFLs, but neither difference is statistically significant. Those who purchased at least one of these lighting products were asked how many they purchased, and this information was used to calculate the average purchase rate.

Table 5. Purchased at Least One (%)

	BC	Dakotas	Difference	Z-test
Incandescent	44.4	52.6	-8.2***	-2.82
Basic CFL	39.6	41.2	-1.6	-0.59
Specialty CFL	10.4	10.8	-0.4	-0.09
LED	12.3	7.7	4.6***	2.69
Halogen	24.7	15.4	9.3***	3.96
Any fixture	21.7	16.6	5.1***	2.20

One, two and three asterisks mean that the coefficient is statistically significant at the 10%, 5% or 1% level respectively.

Survey respondents were asked whether or not they had installed various types of lighting products, and Table 6 shows the survey results for lighting product installation. BC survey respondents show a higher level of product installation than Dakota survey respondents for five of the six product categories, and these differences are statistically significant for three of them. Dakota survey respondents show a higher level of product installation than BC survey respondents for incandescent lamps.

Table 6. Installed at Least One (%)

	BC	Dakotas	Difference	Z-test
Incandescent	60.3	65.5	-5.2**	-1.91
Basic CFL	55.7	54.9	0.8	0.29
Specialty CFL	15.3	13.9	1.3	0.65
LED	13.5	8.3	5.2***	2.87
Halogen	29.9	19.9	10.0***	4.00
Any fixture	21.7	17.0	4.7***	2.05

One, two and three asterisks mean that the coefficient is statistically significant at the 10%, 5% or 1% level respectively.

Survey respondents were asked how influential program activity was in their decision to purchase energy efficient lighting products, and attribution rates were calculated by weighting the responses and finding a weighted average. If spillover is ignored, the attribution rate is equal to one minus the free rider rate, the larger the attribution rate the more influential a program is, and the larger the proportion of reported energy savings attributed to the program. Table 7 shows the attribution rates calculated from customer survey data for specialty CFL lamps and for Energy Star fixtures. The attribution rate for specialty CFLs is 0.81, and the attribution rate for Energy Star fixtures is 0.73.

Table 7. CFL Lamp and Energy Star Attribution (survey based)

Specialty CFL	**Very influential**	**Somewhat influential**	**Not too influential**	**Not at all influential**	**Attribution (1 – free rider)**
Share	0.43	0.57	0.00	0.00	
Weight	1.00	0.67	0.33	0.00	
Weighted share	0.43	0.38	0.00	0.00	0.81
Energy Star Fixture	**Very influential**	**Somewhat influential**	**Not too influential**	**Not at all influential**	**Attribution (1 –free rider)**
Share	0.46	0.30	0.18	0.06	
Weight	1.00	0.67	0.33	0.00	
Weighted share	0.46	0.21	0.06	0.00	0.73

Table 8 provides an attribution analysis for LED lamps and LED fixtures based on reported sales data. Program management was able to obtain sales data for the eight weeks of the fall lighting campaign as well as four weeks before and four weeks after the fall campaign for companies representing some 80% of the market, and this sales information was inflated to represent the whole market. Since out of campaign sales represent base sales levels, one minus (ratio of out of campaign sales to in campaign sales) is the attribution rate. The attribution rate for LED lamps is 0.89, and the attribution rate for LED fixtures is 0.84.

Table 8. LED Lamp and LED Fixture Attribution (sales based)

	Out of campaign sales (8 weeks)	**In campaign sales (8 weeks)**	**Out of campaign/in campaign**	**Attribution (1 – free rider rate)**
LED	5,924	55,474	0.11	0.89
LED fixtures	610	3,797	0.16	0.84

To understand the longer-term impact of the program we build an econometric demand model using annual estimates of residential saturation of energy efficient lamps and prices of energy efficient lamps, as well as awareness of energy efficient lamps and a dummy variable for the Energy Star program period. Data for the period from 1997 through 2008 was used. Both ordinary least squares (OLS) and maximum likelihood (ML) models were estimated. The regression results are shown in Table 9. The estimated models perform well with very high adjusted R-squared and minimal auto-correlation.

Table 9. Demand for Energy Efficient Lamps (log of average installed)

	OLS		**ML**	
	Coefficient	St. dev.	Coefficient	St. dev.
Constant	3.12***	-0.66	3.19***	0.63
Log of price	-1.52***	0.29	-1.55***	0.27
Log of awareness	1.57*	0.72	1.55**	0.67
Program dummy	1.04***	0.29	1.10***	0.28
Adjusted R-sq.	0.99	-	0.99	-
Durbin-Watson	1.89	0.05	2.11	-0.05

One, two and three asterisks mean that the coefficient is statistically significant at the 10%, 5% or 1% level respectively.

Because the regression models are in double log form, the regression coefficients are elasticities, except for the program period dummy variable which needs to be rescaled. Table 10 shows the elasticities based on the demand regression models. These elasticities say that a 1% increase in price reduces saturation of energy efficient lamps by 1.52% to 1.55%, a 1% increase in customer awareness of energy efficient lamps increases saturation of energy efficient lamps by 1.57% to 1.55%, and the presence of the Energy Star Lighting program increase saturation of energy efficient lamps by 175% to 183%.

Table 10. Elasticities (%)

	OLS	ML
Price	-1.52	-1.55
Awareness	1.57	1.55
Program	183.0	175.0

Note. For price and awareness the elasticity is the percentage change due to a one percent change in the forcing variable, but for program the elasticity the elasticity is the percentage change due to the presence of the Energy Star Lighting program.

Hours of Use and Peak Coincidence. The purpose of the hours of use and peak coincidence analysis was to determine annual, seasonal and daily operating hours of use for light fixtures located in different areas of the home. Information collected through the Residential Load Monitoring Study was used to estimate annual hours of use and peak coincidence with sample drawn from BC Hydro's 2008 Residential End Use Survey participants. Lighting end uses (n = 333) were monitored using time of use loggers between June 2010 and July 2011, so that at least 12 months of data was collected for each monitored lamp. Information on location of lamps and fixtures by room was used to weight the monitored hours of use by room to calculate weighted hours of use and peak for lamps and for fixtures. The results of these calculations are shown in Table 11.

Table 11. Hours of Use and Peak Coincidence

	Average hours of use	Peak coincidence
Lamps	2.56	0.31
Fixtures	3.18	0.39

Energy and Peak Savings. The purpose of the impact analysis was to estimate the program impact on energy and peak demand savings for CFLs, LEDs, Energy Star fixtures and LED fixtures and determine the extent of spillover, if any. Key parameters are the difference in watts between the base and the efficient technology, annual hours of use, the peak coincidence rate, the installation rate net of replacements, the free rider, the spillover rate, the electricity cross effects adjustment, and the number of rebated units. For first-year energy savings, the basic algorithm is:

$$\Delta GWh = \Delta W \cdot Hours \cdot Install \cdot (1 - FR + SO) \cdot (1 - CE) \cdot Units.$$

For peak demand savings, the basic algorithm is:

$$\Delta MW = \Delta W \cdot Peak\ Coincidence \cdot Install \cdot (1 - FR + SO) \cdot (1 - CE) \cdot Units.$$

Table 12 shows gross unit savings for lamps and lighting fixtures without spillover. The delta watts estimates were provided by the program based on internal analysis, and the annual hours and peak coincidence estimates came from the Residential Load Monitoring Study. At first glance the smaller level of delta watts for LEDs than for CFLs may seem surprising since LEDs are more efficient than CFLs, but this is due to the fact that LEDs have typically been replacements for lower wattage standard efficiency lamps than has been the case for CFLs.

Table 12. Gross Unit Savings

	Δ watts	Annual hours	Peak coincidence	Unit energy savings (kWh/y)	Unit peak demand (W)
CFL	53	934	0.31	49.5	16.4
LED	44	934	0.31	41.1	13.6
LED fixtures	53	1,161	0.39	61.5	20.7
Energy Star fixtures	110	1,161	0.39	127.7	42.9

Table 13 shows net unit savings for lamps and lighting fixtures without spillover. The estimates of unit energy demand, unit peak demand, the installation rate and one minus the free rider rate are explained above, while the estimate of one minus cross effects comes from a recent internal study by Power Smart engineering staff. For net unit energy savings, the algorithm is:

(5) kWh = ∆kWh · Install · (1 – FR) · (1 – CE).

For peak savings, the basic algorithm is:

(6) kW = ∆W · Install · (1 – FR) · (1 – CE).

Table 13. Net Unit Savings

	Unit energy (kWh/y)	Unit demand (W)	Install rate	1 - FR	1 - CE	Net unit energy (kWh/y)	Net unit demand (W)
CFL	49.5	16.4	0.94	0.81	0.95	35.8	11.9
LED	41.1	13.6	0.82	0.89	0.94	28.2	9.3
LED fixtures	61.5	20.7	1.00	0.84	0.94	48.6	16.3
Energy Star fixtures	127.7	42.9	1.00	0.79	0.98	98.9	33.2

Table 14 shows net energy and demand savings including spillover. Net unit energy and net unit demand come from the previous table, while the number of program incented units was provided by the program. For net unit energy savings, the basic algorithm is:

(7) GWh = Net unit energy savings · Program incented units.

For net peak savings, the algorithm is:

(8) MW = Net unit demand savings · Program incented units.

The evaluated savings were 28.7 GWh and 9.5 MW. This is substantially above the program reported savings of 15.5 GWh and 5.5 MW. The difference between the evaluated and the reported savings is primarily due to the evaluated impact of spillover.

Table 14. Net Total Savings

	Net unit energy (kWh)	Net unit demand (kW)	Units	Net energy savings (GWh)	Net demand savings (MW)
CFL	35.8	11.9	236.532	8.5	2.8
LED	28.2	9.3	140,402	4.0	1.3
LED spillover	28.2	9.3	411,164	11.6	3.8
LED fixtures	48.6	16.3	12,322	0.6	0.2
Energy Star fixtures	98.9	33.2	40,567	4.0	1.4
total				28.7	9.5

Conclusions

Program Design and Implementation. The BC Hydro Energy Star Lighting Program has been successful in increasing product availability, product awareness, product affordability and product acceptability for energy efficient lighting. A significant degree of market transformation has occurred with respect to replacement of traditional incandescent lamps with spiral CFLs. The Energy Star Lighting Program has continued to evolve and now successfully features a wide range of energy efficient lighting products including specialty CFLs, LEDs, Energy Star fixtures, and LED fixtures.

Program Energy, Peak and Price Impacts. Engineering algorithms informed by BC Hydro customer survey, North and South Dakota customer survey data, on-site metering data and a series of shelf stock studies were used to estimate direct program impacts. The program reported energy savings for F2012 of 16.2 GWh per year compared to evaluated savings of 28.7 GWh per year. The difference between the evaluated and the reported savings is primarily due to the evaluated impact of spillover.

Evaluation Methods. Most evaluations of residential lighting programs focus on information based primarily on demand-side or purchaser analysis and in-home metering of hours of use. This study argues that a richer and more persuasive evaluation can be undertaken by supplementing the study with supply –side information collected through shelf stock surveys and interviews with trade allies to collect detailed sales information.

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Systematic market monitoring: a pilot project on TVs demonstrates the value for policy design

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Abstract

The Ecodesign and Energy Labelling regulations, covering a long list of energy using products, can have a strong influence on the market towards higher efficiency. But several decisions on minimum requirements and labelling scales have been taken based on weak and outdated market data. Some of the regulations are assumed to have been missing their targeted energy savings because the policy instruments had not been appropriately designed. A systematic monitoring of the market evolution based on quality data - which does exist – would allow evaluating the effects of policies and serve as a basis for future policy design.

Using GfK market data and in collaboration with WWF Switzerland, Topten has undertaken a monitoring of the TV market in Europe. Market data from 2007 to 2012, covering the entire EU and at the country-level for six countries, has been analysed regarding developments in sales, screen size, price and On mode power. For the 2012 data also the crucial information on the energy efficiency class is included. The results show the market trends towards larger screen size and higher energy efficiency and how the Label and Ecodesign implementing measures (in combination with the new measurement standard) have influenced the TV market.

The results of the TV market monitoring provide a sound basis for decisions in the framework of the Ecodesign regulation for TVs' revision. In addition the project' results demonstrate the value of a systematic market monitoring, when it is based on sound data.

Introduction

Decisions on product policies: systematic market monitoring needed

Based on the Ecodesign Directive from 2005 [1], its recast [2] and the recast of the Energy Labelling Directive from 2010 [3] the European Commission has introduced Ecodesign requirements for 16 product groups and new or updated Energy Labels for 9 product groups since 2005. These implementing measures are estimated to lead to Energy Savings of about 430 TWh annually by 2020 [4]. In 2013 some 15 new implementing measures will be adopted, saving another 360 TWh annually by 2020 [4], and more are to come in the near future. In general, the Ecodesign and Energy Labelling process is a success.

In many cases however, higher energy savings could have been achieved with policy instruments better aligned to the market and technical development. Several of the new Energy Labels need to be revised shortly after their introduction to the market: many products are already in the top-A+++-classes of the new Labels for washing machines [5], dishwashers [6], and tumble driers [7]. In the case of TVs, the Ecodesign regulation is thought to have been of only little impact, because 'the requirements are at a lower level than many products already on the market' [8]. As a key reason for not setting adequately ambitious requirements, the Ecodesign evaluation study [8] identifies 'the absence of up-to-date information on market developments'.

Today, market data is gathered by the authors of the preparatory study, based on which a Working Document is drafted, which is discussed by the Consultation Forum, before a draft regulation is voted. The whole process takes up to 7 years (in the case of the recently adopted Ecodesign and Labelling regulations for boilers and water heaters), and by the time of the application of a measure, the data the decision was based on was out-dated in many cases. Another problem is the quality of the market data: as the budget for the preparatory study does not cover expenses to buy quality market data, the authors have to rely on publicly available data –usually data provided directly by the industry. The data is often only a sample, not sales-weighted and quickly outdated, and is not comparable to data assessed at a later stage for evaluation reasons. The time-consuming task of data gathering is not cost-effective, because it has to be repeated each time a market overview is of interest (preparatory study, impact assessment, evaluation of measures, revision of measures…), while the results are not comparable because different sources and methods have been used. In order to improve the availability of market data to adequately decide on Labels and requirements, Topten International suggests a systematic market monitoring activity in Europe, based on quality sales data. Sound sales data showing the market development in recent years can be bought from market research companies (e.g. GfK) [9]. If in the future a mandatory product registration database is set up, sales data could be linked to this and an annual report on (aggregated) sales development could be produced using the database. It would be more cost-effective to observe the market with a regular (e.g. annual) monitoring, based on sound data that is comparable over time and between countries, than to undertake isolated data gathering tasks whenever the state of the market is of interest. A regular market monitoring for all product categories with an Energy Label allows to react in time and start a revision of the Label before all models are in the top class, and to design new Ecodesign requirements and Energy Labels appropriately so that these instruments, the introduction of which goes hand in hand with high administrative costs before and during their implementation[1], have a maximum effect on the market towards higher energy efficiency. An example of how simple an effective market analysis regarding energy efficiency can be is shown in a recent publication covering Swiss appliances sales data [10 and11].

With the present paper, Topten demonstrates the value of a systematic market monitoring, through the example of a market monitoring on TVs. The study on TVs was realized based on GfK data, and thanks to the support of WWF Switzerland [12] and the European Climate Foundation [13],

The Ecodesign regulation on TVs [14] is the first Ecodesign implementing measure to be revised. The revision process started in 2012 with the publication of a discussion paper [15] and a Consultation Forum. The adoption of the revised Ecodesign and Labelling regulations is planned for the fourth quarter of 2013 [4]. The TV sales data analysed in the present study allows to draw conclusions on the effectiveness of the requirements on On mode power introduced by the 2009 Ecodesign regulation [14] and of the Energy Label adopted in 2010 [16]. At the same time the availability of sound market data will help to support decisions on appropriate minimum efficiency requirements for the revised regulations.

TVs: market development, standards and product policies

The preparatory study on TVs was started in early 2006. At the same time, the measurement standard was revised to introduce a different methodology to measure the TVs On mode power. The Ecodesign regulation on TVs was adopted in July 2009, the Energy Labelling regulation in September 2010. During these years and up to now the market changed dramatically: the formerly dominating Cathode Ray Tube (CRT) TVs completely disappeared from the market and were replaced by flat panel TVs – mainly by Liquid Crystal Display (LCD) TVs. This development was to a large extent drawn by the change from analogue to digital TV broadcasting, the trend to high resolution (HD) displays, and went hand in hand with a trend to larger screens [17]. In 2012 Light Emitting Diode (LED)-backlit LCD-TVs are dominating the market, and current driving forces to market development are trends towards internet connectivity, 3D or ultra high definition TVs [14]. It is expected that in the mid-term Organic Light Emitting Diode (OLED)-TVs will start the next fundamental market change. The most important steps in TV standardization and policy making since 2007 are briefly presented below.

a) August 2007: preparatory study finalised

Started in early 2006, the preparatory study on TVs was finalised in August 2007. Sales data used in the study was from 2003 and 2004, when CRT TVs were still clearly dominating the market. The authors of the preparatory study stated that a fast development was happening at the time of research and that it was ‘difficult to give a precise evaluation of the mid to long term situation’ [17]. LCD and Plasma TVs had newly entered the market and started to replace CRT TVs.

b) October 2008: Publication of IEC 62087:2008 standard

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[1] According to the Evaluation of the Ecodesign Directive [8], 12.5 million Euros were spent between 2006 and 2011 by the European Commission for preparatory studies and a similar amount on staff and other costs.

Already since 2004 experts from major TV manufacturers and independent international experts were involved in the development of the new IEC dynamic test signal methodology [18]. IEC 63087:2008 [19], published in October 2008, was the first international test standard to introduce a test methodology based on a dynamic broadcast signal for measuring the average On mode power of TVs. The authors of the preparatory study recommended basing the Ecodesign and Labelling declarations on this methodology. Before 2008, according to IEC 62087:2003, a static three-bar black & white test pattern was used. Many manufacturers however also declared maximum power, established for safety testing [18].

c) October 2008: Consultation Forum
A working document (WD) on Ecodesign requirements for TVs was discussed at a Consultation Forum (CF). This was not the first WD but a version that had already been updated [20].

d) March 2009: Final Ecodesign draft
The Regulatory Committee approves the final draft Ecodesign regulation.

e) May 2009: Rejection of Energy Labelling draft
The energy labelling proposal is rejected by the European Parliament. The labelling scale in the proposal was based on the ‘A-20%’ format. The Parliament claimed that the Labelling format was confusing to consumers (the same day however the Parliament adopted a new Energy Label for refrigerators and freezers based on the same format) [21].

f) July 2009: adoption of the Ecodesign regulation
The European Commission adopts the Ecodesign regulation on TVs [14]. It enters into force in August 2009, and after one year the requirements regarding maximum On mode power apply. The requirements on Standby and Off mode power (max. 1W / 2W) apply already from January 2010.

g) February 2010: new Energy Labelling draft
A new Energy labelling draft is circulated for stakeholders' comments. The labelling scale is now based on the A+ format, which is in line with the recast of the Energy Labelling Directive to be adopted in May 2010 [3]. The A class limit has been shifted to a 20% more ambitious level compared to the proposal from 2009. Soon after (in March), a classification scale with an even more ambitious class limit is circulated.

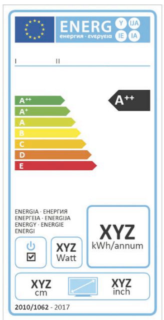

Fig 1: Energy Label for TVs

h) August 2010: tier 1 On mode power applies
New TV models put on the market after this date are required to have a power consumption in On mode corresponding to class F or better (‘normal’ resolution). Full HD TVs can have higher power, as defined in the regulation. Thus, class G is partly banned from August 2010.

i) September 2010: adoption of Labelling regulation
The new Energy Labelling regulation for TVs [16] is adopted by the Commission. The Energy Label with the classification scale proposed in March enters into force in December 2010. The classification scale of the Energy Label is based on the Energy Efficiency Index (EEI), which is also used in the Ecodesign regulation. The EEI expresses the power of a TV relative to the power of a reference model of the same screen size. The EEI and the Energy Efficiency class are thus indicators of the relative power (and energy consumption, as this is directly linked to power). Consequently, a large TV can be labelled with the same or even better Energy class despite consuming more energy than a small TV. The annual energy consumption is also indicated on the label (Fig. 1). It is however questioned whether consumers are responsive to this secondary information figure [24].

j) December 2011: the Energy Label applies
The transition phase of the Energy Labelling regulation is terminated and the declaration according to the Energy Label is compulsory.

k) April 2012: tier 2 On mode applies (class D)
The second step of the minimum efficiency requirement of the Ecodesign regulation applies: new TVs put on the market must be in class D or better.

Present / Future developments:

The Ecodesign regulation for TVs [14] asks for a review of the regulation in 2012. The revision process has started in 2012 with the publication of a discussion paper [15] and a Consultation Forum. The adoption of the revised Ecodesign and Labelling regulations is planned for the fourth quarter of 2013 [4].

Development of the Best Available Technology (BAT)

Topten [23] is an online tool to inform about the most energy efficient products. Topten selects its products according to official Labels and Standards. In 2009 the European Topten website started to list TVs according to the Energy Label draft. The rapidly increasing efficiency of the TVs listed on Topten.eu demonstrates the fast technological development that happened along the discussions and already before the introduction of the implementing measures. In September 2010, when the Labelling regulation was adopted, Topten already listed 60 class B and 5 class A TV models. One year later, when the Energy Label applied, there were 110 class A TVs and 17 A+ TVs on Topten.eu. By April 2012 the number of A+ TVs on Topten.eu has climbed to 99 and the lists showed that the first A++ TVs had emerged on the market [25]. At present, there are more than 170 A+ TVs and 21 A++ TVs on the lists of Topten.eu, despite additional selection criteria such as a strict maximum On mode power of 64W (the model numbers include all similar models on the market. Some might be of similar construction).

Data and Methods

Coverage

GfK [26] is a professional market analysis company present around the world. In Europe GfK covers over 90% of the markets in all 27 Member States. Sales data plus many product characteristics are obtained from retailers. For this market monitoring TV sales data were obtained from GfK, for the years 2007 – 2012. The data covers TV sales in the EU-24 plus additionally sales on country level for six countries (table 1).

Table 1: Countries covered and population

Country	Population[2]
EU-24*	499.3 Mio
Germany	81.7
France	64.7
UK (without Northern Ireland)	62
Spain	46
Poland	38.1
Denmark	5.5

* EU-24 includes Germany, Denmark, United Kingdom, Italy, Poland, Spain, Austria, Belgium, Bulgaria, Estonia, Finland, France, Greece, Hungary, Ireland, Latvia, Lithuania, Netherlands, Portugal, Czech Republic, Romania, Slovakia, Slovenia and Sweden.

For the years 2007 – 2011 sales numbers, price and annual energy consumption as declared for different size categories and TV technologies were retrieved. As power was not available, it was re-calculated from annual energy consumption. From 2008 - 2010 for about 80% of the TVs power was declared according to the IEC 62087:2008 standard. Annual energy consumption was declared according to the calculation formula that was included in the Energy Labelling regulation later ($E = P*1.46$) (for more details on measurement and calculation methods see below). After November 2011 the Energy Label for TVs became compulsory [16]. So, for the 2012 dataset also the energy efficiency class was included. No information on brands or models is included.

Sales of CRT TVs are included in the total sales and in the average price, but no detail information such as size, price or power/energy consumption is available for CRT TVs sold in Poland, Germany and Denmark. After 2010, CRT sales were 0 in these countries, and the missing information concerns only the years before. The details of the data gap are shown in [28].

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[2] Data from Eurostat: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

On mode power – changing measurement methods

Between 2007 and 2010 the declaration of the TVs On mode power changed, because a new measurement methodology was introduced. IEC 62087:2008 was the first international measurement standard to introduce a testing methodology based on a dynamic broadcast signal for measuring the On mode power of TVs. The Ecodesign regulation [14] refers to a dynamic measurement method. Since 2010 On mode power of TVs on the European market is declared according to this measurement method.

Experts were developing the new test standard since 2004 already. Also the authors of the preparatory study recommended the new method based on the dynamic broadcast content signal to be referred to for the Ecodesign and Energy Labelling regulations in 2006/2007 [17]. At the same time it was decided that annual energy consumption would be declared, based on an assumed daily use in On mode of four hours and not considering low power modes. Major manufacturers started to apply this methodology from 2008 [18].

Which of the On mode power testing methods (static 3-bar signal of IEC 62087:2003, dynamic signal contained in IEC 62087:2008 or maximum On mode power as declared for safety testing) and annual energy consumption calculation methods were used in the declarations before 2008 is not known. Additionally before 2010 there was no obligation to declare a power or energy consumption value according to a given test standard. Therefore the power values before 2009 / 2010 should be interpreted with caution. It is assumed that for 2008 – 2009, about 80% of the TVs were declared according to the measurement and calculation methods used today in the Energy Labelling regulation for TVs [18].

Not included: Standby power and total energy consumption

Information on Standby and Off mode power is not included in the TV Monitoring project. These were certainly relevant modes for the energy consumption before the TVs Ecodesign regulation became effective in 2010, and which limited the power of these modes to maximally 2W. Before 2009 Standby and Off mode power were not declared in a standardised way, and since 2010 these low power modes are no longer crucial for the total energy consumption.

The monitoring project does not present total energy consumption values, even though this figure can be calculated from the On mode power and the sales – based on the calculation formula used in the Energy Label. The Labelling regulation assumes a daily On mode duration of 4 hours [16], based on the findings from the preparatory study [17]. The authors of the preparatory study expected that the On mode duration per day would rise to an average of 5 hours in the future. Daily viewing time may differ between countries, but also for different TVs. The DEFRA study 'Powering the nation' from 2012 for instance found an average daily TV watching time of six hours in UK, the average household possessing 2.3 TVs [27]. The study does not differentiate between different TV sets. Assuming that larger TVs are used in the living room than in the sleeping room and that average viewing times for the two TV types differ, this influences the total energy consumption. Considering this, the different methods used for declaring the On mode power over the years plus the decreasing importance of the low power modes (without having information on it) it was decided to only present On mode power figures instead of annual energy consumption. The data presented however allows deriving estimations on the evolution of TVs' energy consumption in Europe.

Results and interpretation

The graphs and results presented below represent a 'best of'-selection. The full results are publicly available in the full report: *European TV market 2007 – 2012: development of energy efficiency before and during the implementation of the Ecodesign and Energy Labelling regulations* [28].

From 2007 to 2010 the number of annually sold TVs increased by 50% - from 37 million to 56 million units per year (fig. 2). These figures impressively show the impact the introduction of new technologies have had – assumedly especially the switchover from analogue to digital TV. After 2010 the sales decreased at a similar pace – back to 47 million units in 2012.

Not only were more TVs bought, but also larger ones: Fig. 3 shows the on-going trend towards larger screens. Between 2007 and 2012 the sales have generally shifted to larger screen sizes. Fig. 3 shows a constant decrease of the sales proportion of very small TVs (screen diagonal < 20 inches) and a constant increase for the two largest size categories (screen diagonal between 40 and 50 inches and 50 to 60 inches). The sales proportions of the intermediate sizes (20'' – 30'' and 30''- 40'') show less clear trends but some fluctuations over the observed years. This graph can be interpreted

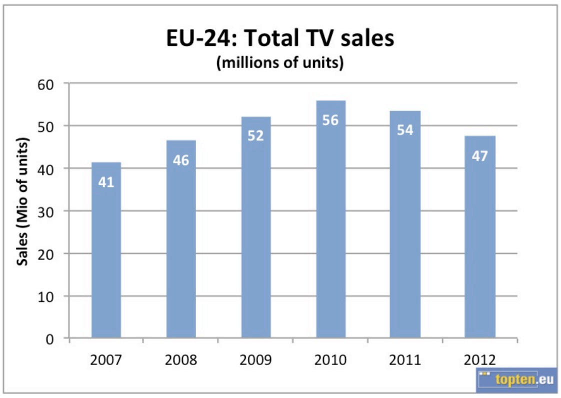


Fig. 2: Total annual TV sales in the EU-24

Data source: GfK

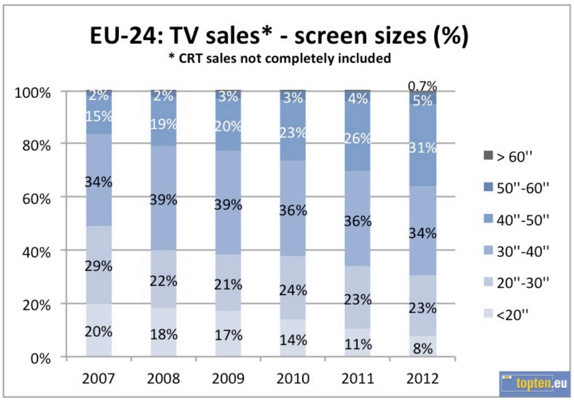


Fig. 3: TV sales in the EU-24: percentage of different screen size categories

'' = inches; 1 inch = 2.54 cm. Data source: GfK

with the trend towards two or more TVs per household in mind. While living room TVs are clearly getting larger, TVs bought to be placed in bedrooms will usually be smaller. Looking at the detail screen sizes and the 2012 EU sales, 32'' and 40'' – 43'' turn out to be by far the most popular screen sizes: these two categories together accounted for 53% of the sales in 2012 (32'': 29%; 40'' – 43'': 24%) (graph in [28]).

From 2007 to 2012 two interesting market transformations regarding technology happened: CRT TVs disappeared completely from the market and were replaced by flat panel TVs (LCD and Plasma), and the first generation of LCD-TVs (with Cold Cathode Fluorescent Lamps (CCFL)-backlight) was replaced by the next LCD-generation, using LED for the backlight (fig. 4). The Plasma technology never reached the breakthrough and the sales share always remained below 10%. Also Rear Projection TVs ('Rear Pro') do not reach a noteworthy market share.

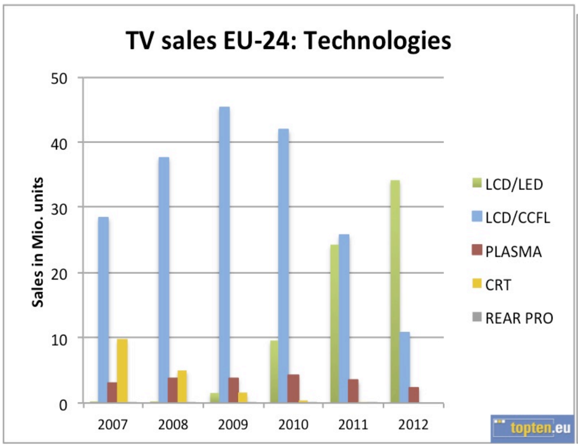


Fig. 4: EU-Sales of different TV technologies

Data source: GfK

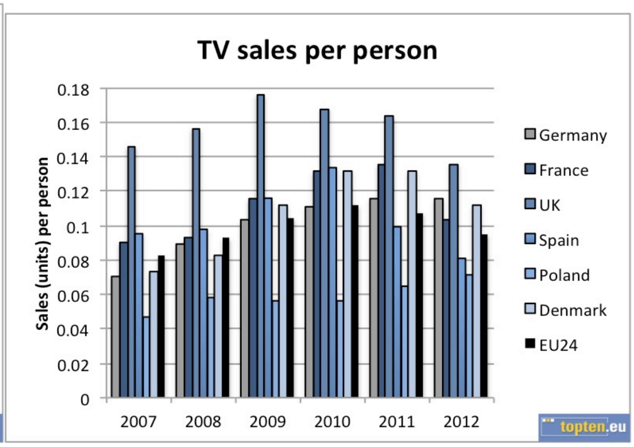


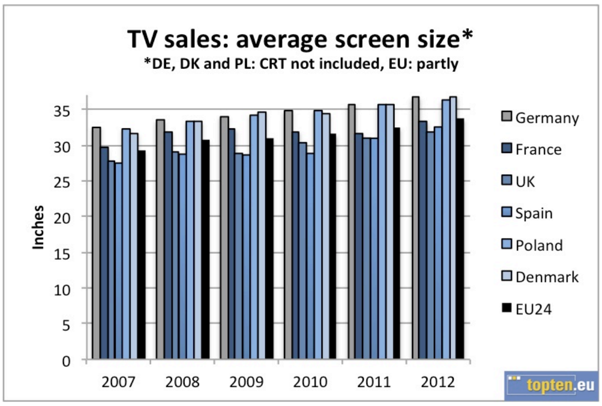
Fig. 5: TV sales per person

Data source: GfK

People do not show the same readiness to buy new TVs all over Europe; there are considerable differences between countries (fig. 5). Most striking is the buying behaviour of UK consumers: in 2007 the British bought almost twice as many TV sets per person as the EU average. At the other end of the scale is Poland: from 2007 to 2011 Polish were around 50% less likely to buy a new TV than the EU average. Contrary to the other countries however, sales in Poland continued to increase until 2012.

Fig. 5 cannot be interpreted without also looking at fig. 6, which shows the trends in average screen size in the countries. As fig. 3, also this figure impressively shows the strong and on-going trend towards larger screen sizes. Across the EU-24, the average screen diagonal increased from 29.3” (74.4cm) by 4.5 inches (+11.4 cm) to 33.7” (85.6cm) between 2007 and 2012 – equalling an increase of 15%.

Fig. 6 also shows that in the UK, where people buy most TVs, they buy smaller TVs than in other countries. UK is a very mature TV market with an average of 2.3 TV sets per household [27]. The smaller average size will be a result from a high sales percentage of secondary TVs, which are placed in the sleeping room or kitchen. These TVs are smaller than living room TVs. The contrary applies to Poland, where comparatively few but rather large TVs are sold. Are these mostly living room TVs, and therefore on average larger? The number of TVs Germans buy is close to the European average, but the average screen size is among the largest. In France the trend towards larger screen size stopped in 2008, the sales per person remained near the EU-average. Also in Spain TV sales per person were near the EU-average, but dropped to lower values in 2011 and 2012. The average screen size however was higher in these two years, after having been among the lowest before. Danish TV consumers compete with Germans and Polish for the largest average screen size, while sales per person increased to values a bit higher than the EU average. When dividing the sales by the number of households instead of persons and thus considering for different household sizes, the outcome is not changed much, but some of the differences between countries become smaller [28].



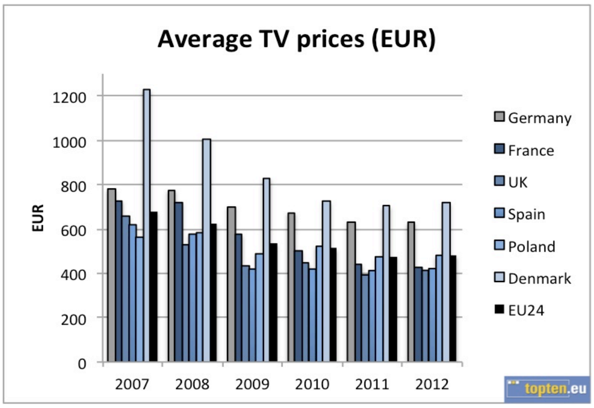


Fig. 6/7: TV sales– average screen size / Average TV prices in EU and countries

Data source: GfK

Despite growing screen sizes, average TV prices in general decreased from 2007 to 2012, at a slowing rate which seems to have stopped in 2011. Average price reduction in the EU was 29% from 2007 to 2012, but around 50% when looking at certain size categories and thus minimising the effect of increasing average screen size [28]. The price decrease over these years was smallest in Poland (-15%) and Germany (-19%), and strongest in Denmark (-42%) and France (-41%). Not surprisingly, the two countries with lower average screen size, UK and Spain, also pay the lowest average prices for their new TVs. Prices in Poland have been similarly low, probably mostly due to the rather low Purchasing Power (PP)[3]. French average prices decreased to be among the lowest after 2010, more or less in line with shrinking screen sizes. In Denmark, which has the highest PP of all EU Member States, the highest average TV prices are paid.

The analysis of the 2012 data in the full report [28] shows that TV prices are closely linked to screen size, but not to energy efficiency.

Larger TVs (of the same technology) have higher power in On mode [17] – this easy-to-understand rule which is also embedded in the EEI calculation formula of the Ecodesign and Energy Labelling regulations (larger TVs can have higher power), leads us to fearing that the strong trend towards

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[3] Source: Eurostat

http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Comparative_price_levels_of_consumer_goods_and_services

larger screen sizes observed above goes hand in hand with higher average On mode power. Fig. 8 makes clear that this fear is not justified: despite the TVs getting larger, the declared average power in On mode has dramatically decreased, especially between 2008 and 2012.
As mentioned in the chapter 'Data and Methods', On mode power values before 2010 have to be interpreted with caution. Before 2010 manufacturers were not obliged to declare power values, and before 2009 different and changing measurement standards were used. Despite these restrictions there are no large discrepancies or jumps in the power values from 2007 – 2009. From 2007 to 2008 the declared average power values increased a bit – probably due to the application of the new measurement method IEC 62087:2008. When going more into detail and looking at certain sizes and technologies, the graphs in the full report [28] show a power 'jump' especially for Plasma TVs, while there was little change in the average power of LCD TVs. It is not known according to which measurement standards the On mode power was declared before 2008, and we'll only consider the information from 2008, when assumedly most manufacturers would use the same method as recommended later for the Energy Label, when looking at the development in On mode power,

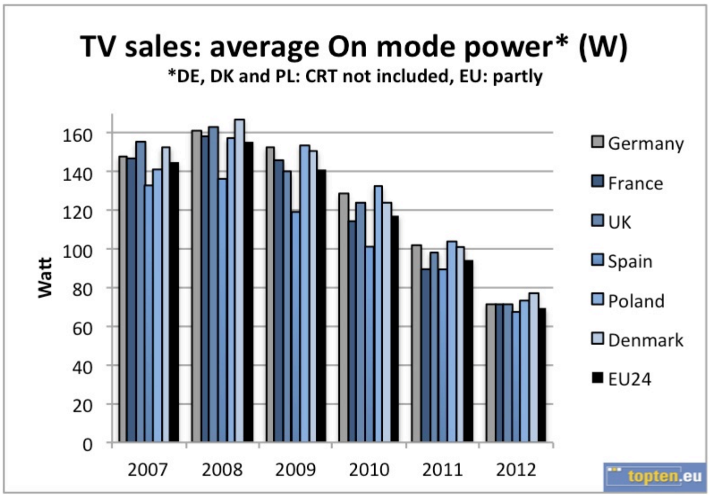


Fig. 8: Average TV On mode power

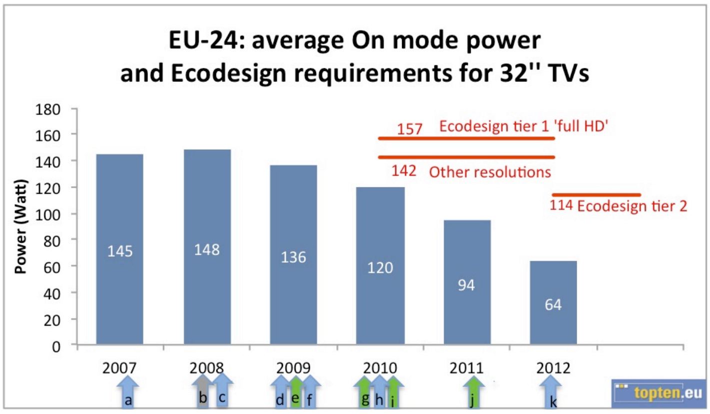
Data source: GfK

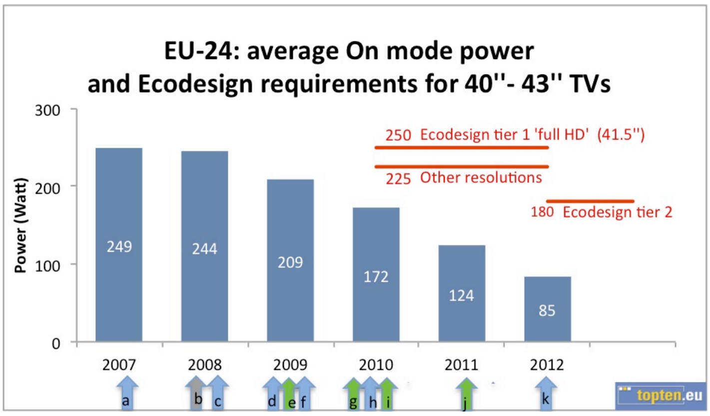
After 2008 the average power of TVs decreased continuously: from 2008 to 2012 the average On mode power of TVs sold in the EU-24 decreased by impressive 55% - despite an average screen diagonal increase of 10% over the same period. In 2008 the average TV sold in the EU reached an On mode power of 156W – by 2012 the average On mode power was 70W.

Not surprisingly, average power is higher in those countries with large average screen sizes: Germany, Denmark, Poland. In Spain and, from 2010, France, where consumers preferred smaller TVs, average On mode power is lower. The average power of TVs in UK was close to the European average, even though average TVs are smaller in UK than in the EU average. The differences between countries became smaller over the years. Especially in 2012, average power is much more levelled across the countries than before. Graphs 9 and 10 show that this cannot be the effect of the On mode power Ecodesign requirements (because their level was clearly above the average power). Was it the effect of the newly compulsory Energy Label, leading manufacturers to design their models along the energy class limits? Another factor is certainly the number of market players that was reduced: the number of different TV brands available on the EU market declined from 746 in 2007 to 480 in 2012 (minus 36%; source: GfK). It is thinkable that the market transformation process towards flat panel and especially LED-backlit LCD TVs eliminated a number of market players, who could not keep up with the pace of development and dropped out of the competition. The reduction of competitors may have lead to a reduction of product 'diversity' on the market and thus contributed to a more uniform market also regarding average power in different countries.

The reduction in average On mode power is impressive. But the graph does not answer the question on the role of the Ecodesign regulation in this development. Obviously most of the trends leading to higher efficiency (e.g. flat panel TVs, LED-backlight) had started a long time before the implementation of the Ecodesign regulation. So, does the graph above show a 'natural' market development that would have equally happened without implementing measures, or did the Ecodesign regulation lead to the product improvement? Toulouse et al. [24] state that the On mode power requirements of the Ecodesign regulation had practically no impact on the market, because both tier 1 and 2 requirements were already met by most main manufacturers. Also the Evaluation of the Ecodesign Directive from 2012 [8] concludes that the Ecodesign requirements for TVs were at a lower level (in terms of energy efficiency) than many products already on the market, while more ambitious requirements could have been introduced.

The detail market data on power for specific screen sizes here allows to investigate this question further. In order to find out more about the effect of the Ecodesign regulation we need to look at certain screen sizes, since the 'cut-off' level of the Ecodesign regulation is dependent on the screen size. The two most popular screen sizes (32" and 40" – 43") are selected for the detail analysis regarding On mode power development. The arrows in the figures 9 and 10 indicate the progress in standardisation and policy making and implementation. It should be noted that before decisions were taken, yearlong discussions including the industry (and some other stakeholders) took place. Many manufacturers were aware of the standards' and regulations' content some time before their publication.





a) August 2007: preparatory study finalised

b) October 2008: Publication of IEC 62087:2008

c) October 2008: Consultation Forum

d) March 2009: Final Ecodesign draft

e) May 2009: Rejection of Energy Labelling draft

f) July 2009: adoption of Ecodesign

g) February 2010: new Energy Labelling draft

h) August 2010: application of tier 1 On mode power

i) September 2010: adoption of Labelling regulation

j) December 2011: application of Energy Label

k) April 2012: application of tier 2 On mode power (class D)

Figs. 9 + 10: Average On mode power and Ecodesign requirements for 32'' and for 40"-43"TVs

Data source: GfK

For the 40'' – 43'' TVs, the Ecodesign limits were calculated for a screen size of 41.5 inches. Between 2008 and 2012 the average On mode power decreased by 57% to 64W for 32'' and to 85W (-65%) for 40'' – 43'' TVs.

Tier 1 of the Ecodesign requirements on On mode power applied from August 2010. For both screen sizes considered here the level of tier 1 was close to the average power from 2008, but clearly higher than the average power in 2010. For 32" TVs the limits were 31% (full HD) and 18% (other resolutions) above the average power, for 40" – 43"-TVs 45% (full HD) and 31% (other resolutions). The percentage of full HD TV sales was not assessed in this study.

In April 2012 the tier 2 On mode power requirement applied, corresponding to class D. A quick glance forward at fig. 11 shows that class D had almost entirely disappeared from the EU-market in 2012, and that this measure must have been of very little impact: only 1% of the TVs sold in the EU in 2012 were class D TVs – the least efficient class still allowed on the market. For both screen size categories in figs. 9 and 10 the average power of the complete 2012 sales was even more below the Ecodesign limit than for tier 1: for 32'' TVs the average On mode power was 78% lower than the second Ecodesign limit, for 40'' – 43'' TVs the average was even 113% lower. The average power of this latter size category was below the tier 2 limit in 2010 already.

Based on these figures we can agree with the studies mentioned above [24 and 8] and conclude that, for the two most important screen sizes, all On mode power limits of the Ecodesign regulation had practically no impact on the market. The efficiency development was happening anyway, the Ecodesign regulation did not have any effect on it. The discussions about energy efficiency may however have supported the technological development to focus also on this aspect, and not only on increasing screen size and additional functions.

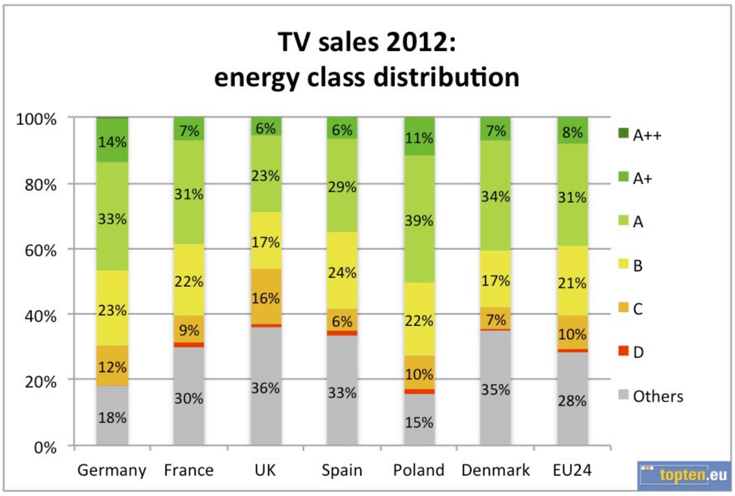


Fig. 11: Energy efficiency of TV sales, 2012

Data source: GfK

Fig. 11 comes close to the simple type of graph we are suggesting to update and publish on an annual basis for all products with an Energy Label in place: evolution of the efficiency, shown in the classes, over the years (as in [10]). Because for TVs the Energy Label was only compulsory after November 2011, such 'dynamic' graphs for the different countries will only be possible from next year. Figure 22 shows the distribution of the 2012 sales on the Energy Classes in the countries and the EU-24. 'Others' include sales of models that were marketed before December 2011 and were not required to have a label, and new models, for which the label information was missing. Fig. 11 lets us draw interesting conclusions:

- In the first full year of the new Energy Label, between 29% (UK) and 50% (Poland) of the sold TVs were in class A or better. Across the EU 39% were in class A or better.
- Class D is no longer visible on the market (EU: 1%). Class D corresponds to the tier 2 power limit enforced in April 2012.
- 6% (UK) to 14% (Germany) of the sales were of class A+, across the EU A+ accounted for 8% of the sales. This class was not expected to appear on the market before 2014; only then will this class have to be shown on the Energy Label.
- For many models the information on the Energy Class was missing: between 15% (Poland) and 36% (UK) of the sold TVs were not labelled. The EU-average is 28%. These figures also include models that were marketed before December 2011 and do not need to have the Label. A figure containing only data on 2012 models in [28] shows that also many of the new models were sold without Energy Label (21% across the EU).
- The most important class regarding sales share in 2012 is class A: class A has the largest sales share in all countries observed. Across the EU, 31% of all TV sales were class A TVs.
- Once again, differences between countries are considerable. Quite surprising is the high sales share of A and A+ TVs in Poland. The explanation might be linked to the findings above

that consumers in Poland buy larger (but fewer) TVs than in other countries and that larger TVs reach better efficiency classes.

- The possibility to provide an overview on the efficiency of the market with simple graphs like fig. 11 is one of the strengths of a compulsory Energy Label. The opportunity to observe the market development on a regular and systematic basis should not be missed.

Conclusions

General

The reduction in average declared On mode power of 55% between 2008 and 2012 is impressive. The gains in efficiency on a power per screen area basis have been clearly stronger than the trend to larger screen sizes. What this means for the effective electricity consumption by TVs is however not clear. Several factors drive the electricity consumption to higher values than declared for single TVs or to higher values than some years ago for the entire EU (more details in [28]):

- The real average TVs use duration in On mode, and of primary and secondary TVs, is not known and has most likely become longer than before the market transformation to flat panel TVs.
- Real On mode power is in most cases higher than what is declared, up to 30% according to [30].
- Only in 2012 the average declared On mode power was back at the level of the On mode power the old CRT TVs [28]. The sales peak in 2009 – 2010 occurred before the efficiency gains through technological development made up for the increased functionality and screen size of the flat panel TVs. These 'energy hungry' TVs remain installed for the next decade or so.

Evaluation of Ecodesign requirements and Energy Label

Ecodesign requirements on On mode power

The results show that the development towards lower power in On mode has started in 2008 / 2009 and that the development was much faster than anticipated. The development towards better efficiency seems mainly to be linked to the new technologies that were introduced, especially LED-backlit LCD-TVs. The efficiency development clearly outran the Ecodesign regulation, which was left without any impact.

According to the Ecodesign Directive [1] the minimum requirements should be placed at a level which aims at the Least Life Cycle Cost (LLCC) for consumers. Because the question on the credibility of the data provided by the industry lead to intense discussions and because it was difficult to predict the market development based on the data at hand, the Commission decided to define cautious minimum requirements but to include an early revision date [23].

However, when the Ecodesign regulation was adopted in mid-2009, even the availability of sound data on average On mode power like the one presented here would not have much helped the Commission to define more appropriate power limits. The trend towards lower power started only in that year, and because of changing measurement standards and no obligation to declare standardised power values, also the data up to 2008 would not have allowed to predict the fast development of the years to come. Only manufacturers might have been able to make more adequate estimations.

Energy Label

With the Energy Label for TVs, a brand new Label was designed. Since there was no existing older Label, there was no resistance about possible downgrading of existing products, and clearly the original A to G scale should have been aimed at. This is what the Energy Labelling Directive [3] stipulates: "The format of the label shall retain as a basis the classification using letters from A to G (…)". And only the next paragraph adds the possibility to go beyond A if needed: " Three additional classes may be added (…) if required by technological progress. Those (…) will be A+, A++ and A+++ …". However, already in the first year of the Label being compulsory, 8% of the products were in class A+ across the EU. A+ was not expected to be reached before 2014 and therefore does not have to be displayed on the Label. Obviously the development towards higher efficiency has been faster than anticipated when the Energy Label was designed in 2010.

However, also when the Energy Label was adopted, the rate of improvement to come was difficult to be predicted – even with more up-to-date data at hand. With data up to 2009, only the beginning of the efficiency development could have been observed, and the sales share of LED-LCD-TVs was only 3% in that year and just starting to grow. The number of TV models on the product lists of Topten.eu [25] shows that a rising number of models met the class B limit, but only very few the class A limit at the time of adoption.

A positive point is that, contrarily to the situation for most Labels that have been revised (refrigerators, washing machines, dishwashers, tumble driers), the top class of the TV energy Label is still empty [6]. Also the A++ limit seems yet to require a lot of technological efforts and the use of the discount granted for Automatic Brightness Control (ABC) [30]. The current Energy Label continues to provide an incentive for further efficiency developments.

In addition the Label now provides a basis for a continuous and easy market monitoring, and it will be interesting to see if the market continues to evolve at the current pace – or even faster, now that the Label is in place.

Combined effect

The Ecodesign regulation and Energy Label did have only a faint influence on the trend towards higher efficiency of TVs. It can however be questioned whether without power and energy consumption of TVs being a topic of interest, information obligation, minimum requirements, and the possibility to market high efficiency TVs with a good label class, manufacturers would have used the new technologies to the same extent. The improved measurement standard combined with the introduction of the implementing measures has certainly supported the market development towards better efficiency.

Recommendations for revision

The revised Ecodesign regulation on TVs must avoid setting requirements that would not be ambitious enough and only leading to administrative efforts without effect. The market overview provided in the present paper can be used for more precise prognoses about the future market development. The insights gained here can support the setting of ambitious minimum requirements. Today's class A should be defined as minimum requirement from 2015, A+ announced as second step.

At the same time the Energy Label should be revised to restore the original A to G scale. Class A could be the 'incentive' to be reached by future, even more efficient TVs, and correspond to today's class A+++. Today's best TVs are in A++ [6]. Considering the fast efficiency development of the last few years and the even more efficient OLED technology, which is expected to enter the market in the future, a future-oriented labelling scale is appropriate.

Another point that should be tackled is the strictly linear relative efficiency approach. The current EEI formula and Labelling classification scale allow large TVs to reach a good Energy Class despite consuming more energy than smaller TVs (which can get a worse classification). This approach does nothing to stop the continuing trend towards larger screen sizes, as shown in fig. 6. Up to now, the increasing efficiency of the products has the stronger effect on average power than the growing screen sizes, and average power has been decreasing dramatically in the last few years despite TVs getting larger. At some point however the efficiency potential will become smaller, and a Labelling / Ecodesign approach favoring large TVs will impede reaching the targeted energy savings. Therefore a digressive or even capped approach (like Energy Star Version 5.0 for TVs, which introduced a maximum power in On mode of 108W in 2011 [31]) should be considered for this revision, for both the Ecodesign requirements and the Energy Label.

Systematic market monitoring is essential

Whether the European Commission would have been able to define more appropriate Ecodesign requirements and Energy Label, had there been market data at hand the way it is presented here is not clear because there were changes in the measurement standards, no declaration obligation and a very fast technological development. With the present situation with an Energy Label in place, it is however easy to track the market. The chance for a systematic market monitoring must not be missed. The data exists - professional market analysis companies like GfK collect the data anyway – mainly for their primary costumers, the industry and retailers. The data is not too expensive, and it is more cost-effective to buy it and analyze aggregated figures, which needs not consume much time, on a regular basis than to hire consultants to search for freely available data whenever a revision or an impact analysis is due. The data presented here is up-to-date, complete (covering all countries, manufacturers, technologies, …), sales-weighted and the assessment method remains the same. Therefore it can be compared between countries and over time, which is not true for the data now collected for preparatory studies and impact assessments. On a longer term sound, aggregated sales data could also be provided by a mandatory product registration database – if such a system is set up in the future. A systematic market monitoring based on sound data allows seeing in advance if the Ecodesign and Labelling regulations need to be revised. It allows evaluating the effect of implementing measures, and it serves as a sound basis for the decision on the level of the revised Ecodesign requirements and Labelling scales. After some years (equaling the average lifetime of a product) the data can serve as a basis for quite precise models on the development of the energy consumption by the stock of the monitored products across the EU. With high quality data at hand, the time-consuming task of data collection and discussions about the credibility of the data are unnecessary. The policy making process can be sped up, and the resulting regulations will be of higher impact. Therefore, a systematic market monitoring - based on sound market data – in Europe is a need, for all product categories with an Energy Label.

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The electricity consumption of household appliances in the European Union and the effects of existing EU energy efficiency policies on its evolution

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Abstract

The final total electricity consumption of the residential sector in the EU-27 has increased by almost 40% in the period between 1990 and 2010. Excepting a slight decrease in 2007, the annual variation trend of final per capita electricity consumption has been always positive during these two decades. However, important improvements in the energy efficiency of practically all domestic products consuming electricity have been achieved in the recent years and have contributed to lower the overall EU electricity consumption growth rate. The merit of this certainly goes also to EU and national energy efficiency policy measures so far implemented and expected to allow achieving a further and significant amount of energy savings by 2020. Nevertheless, the number and the capacity of models installed and consuming electricity in the households is raising, products are used for longer periods of time and many of them have more functions or special features that require more electricity. This trend weakens and sometimes counteracts the expected impacts of energy efficiency improvement measures.
This paper aims to analyse the present status of electricity consumption of domestic products and the energy efficiency progresses recently registered for each of the main product categories commercialized in the EU. The main energy efficiency policies implemented at the EU level in the residential sector are also described together with their expected impact on electricity consumption. Finally the paper identifies the main areas of possible improvement concerning the process leading to the implementation of these policies. These areas relate to the duration of the preparatory studies and their synchronization with the standardization activities needed, to the enforcement of market surveillance activities, to the definition of policy measures aiming at limiting the total energy consumption and not just the energy efficiency of products installed by households.

Key words

Electricity consumption, domestic appliances, energy efficiency policy

Introduction

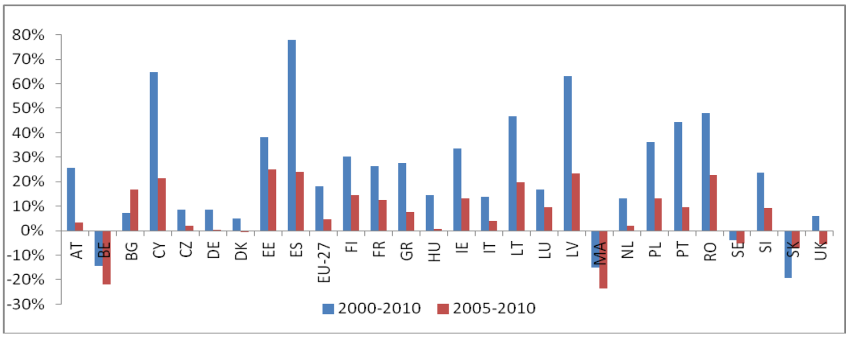
This paper describes the total final electricity consumption trends recently registered in the EU residential sector and complements this description with an analysis of the energy impacts and the effects of the energy efficiency improvements recently observed in the main residential electricity end-

uses. This allows drawing some general conclusions concerning the overall effects achieved by EU energy efficiency policies addressing these end-uses and the main areas of improvements for these policies.
The overview of the existing trends in the total final electricity consumption of the residential sector is based on the information presently available in the literature and in the Eurostat database. The breakdown of this consumption in the main electricity end-uses presented in the paper is instead the result of an on-going survey of statistical data performed by the Joint Research Centre of the European Commission and of the analyses presented in several studies and reports as of 2006.
The impacts on the EU electricity consumption and the energy performance trends of the main product categories installed in the households are described mainly based on the information available in the literature and in the preparatory studies performed by the European Commission for the implementation of the EU 2009/125/EC establishing a framework for the setting of eco-design requirements of energy-related products.

Overview of existing trends in the electricity consumption of the European Union

The residential final electricity consumption in the EU-27 accounted for 29% of the total final electricity consumption in the year 2010. In this year, the residential sector was the second major electricity consumer after the industry sector (36%) and achieved the same amount of final electricity consumed by the service sector [1]. Its annual electricity consumption results to have always increased with respect to the consumption of the previous year, at least since 1990 and with the exception of the year 2007[1]. The total residential electricity consumption grew by 40% in the EU-27 between 1990 and 2010, whereas it grew by 39% in the EU-15 and by 42% in the 12 New Member States (NMS-12) in the same period. In 2010 it reached 843 GWh in absolute terms in the EU-27; its highest point in 20 years.
When it comes to residential electricity consumption per capita, it can be observed that this consumption shows a same trend with a slower annual increase compared to total residential electricity consumption in the period between 1999 and 2010[2].
Concerning electricity consumption at the national level, the following 4 EU Member States (MSs) have registered negative growth rates in the period between 2000 and 2010 (see figure 1 below): Slovakia (-20%), Malta (-15%), Belgium (-15%) and Sweden (-4%). The ones with the highest growth rates were Spain (78%), Cyprus (65%) and Latvia (63%). The number of EU MSs with negative growth rates in residential electricity consumption in the period between 2005 and 2010 is instead 6. Besides the countries previously mentioned, also UK and Denmark managed to achieve a negative growth rate respectively of -6% and –1% in this period.

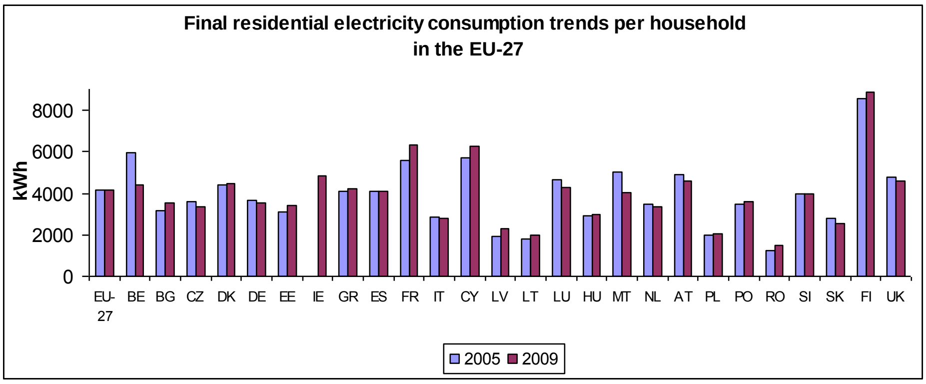
Figure 1: Final residential electricity consumption growth rates in the EU-27 (source Eurostat, JRC)



[1] In 2007 the residential total final electricity consumption decreased by 0.8% compared to the previous year. This can be related to the higher winter temperatures registered during 2007 (implying less electricity use for heating).
[2] In the EU-27 per capita residential electricity consumption was around 1470 kWh in 1999 and around 1680 kWh in 2010. In the EU-15 this consumption was instead around 1680 kWh in 1999 and around 1880 kWh in 2010. In the NMS-12 it was 725 kWh in 1999 and 900 kWh in 2010 (source Eurostat).

Per dwelling residential annual final electricity consumption was around 4100 kWh in the period between 2005 and 2009 in the EU-27[3]. As happened for the total EU electricity consumption, a slightly lower consumption was achieved in 2007 probably due to the unusually higher winter temperatures registered during this year.
The residential final electricity consumption per household shows a large dispersion across EU MSs (see figure 2). The highest residential electricity consumption per household has been registered in Finland. This is mainly due to its above EU-average household electricity consumption for heating and to the use of saunas which can be found in many Finnish houses[4]. It can also be observed that per household consumption variation between 2005 and 2009 is positive for some Member States, e.g. Finland, France and Cyprus, whereas it is negative for other Member States like, for instance, Belgium and Germany. Clearly, the average consumption per household shown results from an average over a wide variety of different household types.

Figure 2: Residential per household final electricity consumption trends in the EU-27 (source Eurostat)



Unfortunately, information and data available do not allow establishing with certainty whether the consumption trends so far described may be correlated to the variations of parameters like energy price, GDP, economies structural changes, degree days, technology energy efficiency improvements as registered at the national level in the EU MSs. Concerning energy prices, considering that the average electricity price increase between 2007 and 2011 has been of 9.72%[5] and given the low elasticity of electricity demand, it seems however quite unlikely that this increase alone may have significantly affected these trends. In any case, a detailed analysis of possible correlations would be surely worthwhile and would deserve more attention. The following paper sections can only try to highlight which are the trends in the diffusion and in the energy performances of existing domestic technologies in order to provide qualitative indications concerning potential correlations between technologies diffusion and energy performance trends and overall electricity consumption in the residential sector. These qualitative indications might represent the starting point for detailed and quantitative correlation analyses that could be undertaken in the future.

Residential electricity consumption breakdown and existing trends in the different end-uses

A breakdown of total electricity consumption is reported in the graph below (see figure 3 below) for the main electricity end-uses. This graph represents a Joint Research Centre (JRC) electricity consumption breakdown resulting from an on-going survey of statistical data and analysis presented in several studies and reports as of 2006. The estimates are in line with other similar consumption breakdowns such as the REMODECE project consumption breakdown [5]. They are also similar to the results of the analysis available in [4].

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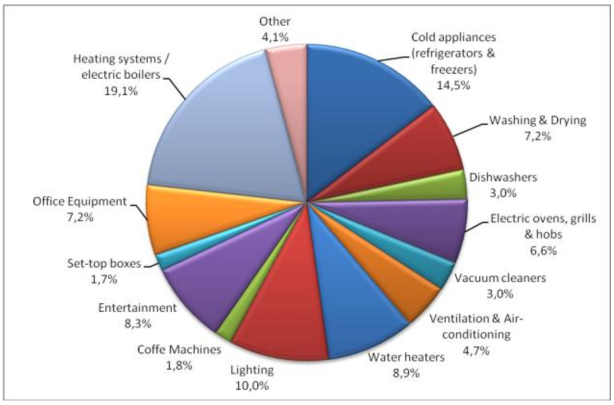
[3] Source: Eurostat
[4] It is worth mentioning that Finland and Sweden had the highest mean heating degree days in the EU-27 in the period between 1980 and 2004.
[5] Source: Eurostat. Datum referring to households consuming around 3,500 kWh/year.

Figure 3: Residential electricity consumption breakdown in the EU-27, 2009 (source JRC)

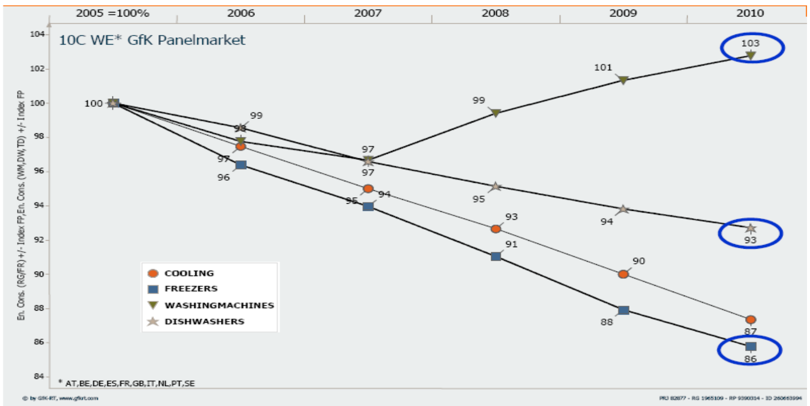


The picture above shows that electricity consumption for thermal uses (i.e. for space and water heating) has by far the highest share among the different electricity end-uses in the residential sector. Existing analyses indicated indeed that electricity consumption for thermal uses is above 20% in all EU countries excepting Romania, Slovakia, Lithuania and The Netherlands, whereas it is around or above 50% in Estonia, Sweden, France, Czech Republic and Ireland [4].
The following of this section is dedicated to a brief quick overview concerning the impact of the main household appliances on the overall EU electricity consumption and the recent developments in their energy performances. This will allow to get qualitative indications about possible areas of future policy intervention and the impacts of the current energy policies. Data concerning total electricity consumption in the EU of the existing appliances stocks are mostly taken from the EU Commission preparatory studies for the implementation of eco-design regulations.

White appliances

White appliances include refrigerators and freezers (cold appliances), washing machines, dishwashers and dryers.
According to GfK[6] data, the average annual consumption per appliance of these 4 product groups in 23 EU countries[7] was 246 kWh in 2010 and decreased by 7 % compared to the average of 265 KWh in 2005. Data available for Western EU (see figure 4 below) indicate that the average energy consumption of new products in Western EU was cut down by 7-14% depending on the category since 2005. The exception is washing machines due to higher loading capacities, as further discussed in the following.

Figure 4: Average energy consumption trends of new products in Western EU (source GfK)



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[6] GfK is an international market research organization providing services in customer research, retail and technology, media (see www.gfk.com for further information).
[7] The 23 EU countries considered for the average were AT, BE, DE, DK, ES, FI, FR, GB, GR, IT, NL, PT, SE, BG, CZ, EE, HU, LT, LV, PL, RO, SI, SK.

Cold appliances

Over the last years, the refrigerator stock reached the saturation level with penetration rates of around 100% in almost all EU-27 countries. At the same time, the freezer market registered a significant decreasing tendency, due to the increased use of combined refrigerators/freezers [7].
The energy consumption of the cold appliance stock was estimated to be around 82 TWh/year for refrigerators and 40 TWh/year for freezers in 2005 [6].
In the five years between 2005 and 2010 the market share of cold appliances with NoFrost technology increased from 16% to 25% [1]. Appliances with NoFrost Technology are more practical for the consumer but also have higher energy consumption than cooling appliances without NoFrost technology. The trend shows that the NoFrost technology will continue to grow in the future. At the same time a recent Gfk panel survey of Western Europe shows that energy efficient appliances on the cold appliances market became less expensive over the last 10 years indicating that existing market conditions can actually stimulate energy efficiency improvements in the existing stock[8].
Despite the significant energy efficiency improvements achieved and the still relevant energy saving potential, the total energy consumption due to domestic cold appliances seems however destined to increase due to the increase in the household number and second appliance ownership.

Washing machines

Also the washing machines market has reached the saturation level with penetration rates of up to 100% in all EU-27 countries.
The Eco-design preparatory studies of the European Commission estimated an energy consumption of the washing machine stock in 2005 around 51 TWh/year, with an average yearly consumption per appliance of 295 kWh in the EU-27 households [7]. The energy consumption of the washing machine stock has increased between 2005 and 2009 mainly because of a continuous increase in the number of washing machines installed [8] and because of an increase in the number of washing cycles and in the load capacity of the new appliances bought [1]. Topten[9] identifies nowadays the ten most energy efficient products on the EU market every year and the most energy efficient washing machine with loading capacity smaller than 8kg[10] results to have an energy consumption of 158 kWh/year and 0.9 kWh/ 60°washing cycle.

Tumble driers

The market of tumble driers instead did not transform as fast as for example the cold appliance market. In 2005, 90% of appliances sold in the EU-25 were in the class C of the existing energy labelling scheme, and the overall consumption of the existing stock was 17 TWh (including both air vented and condenser driers). In 2007, the share of class C appliances dropped to 75% of all driers sold in the EU-20[11] and 16.7% of appliances sold were class B. The share of class A appliances was still very small with 1% [7]. In 2008, the sales share of A-class driers was already significant in some EU Member States, for example in Italy this share was over 10%.
As for washing machines, the average loading capacity of tumble driers has been increasing in the last years. In the year 2000, the average capacity of models available was 4.9 kg. In 2008, eight years later, the average capacity was 6.6 kg. Tumble driers became more efficient during this period: the product weighted performances fell from 0.71 kWh/kg to 0.59 kWh/kg.[12] However, this does not necessary imply that the energy impact of these appliances has or will be reduced in the future. Energy efficiency improvements may indeed have been due to the commercialisation of appliances with higher volumes which typically consume more electricity but have higher performances per weight unit dried. On the other hand, considering that this market is not yet saturated, it may happen that the reduction of energy consumption due to better energy performances of new models can be nullified by an increased product market penetration due to new buyers. Where possible, reducing tumble dryers usage through more use of natural air drying could very effectively reduce the electricity consumption these appliances are responsible for. In general the use of tumble dryers appears to be strongly affected by the cultural differences existing in the various EU MSs, by regulations banning outdoor clothes drying and by structural factors (e.g. linked to the reduced average dwellings' size) impeding that clothes can be dried indoor by natural air.

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[8] In February 2011, the average price of an A+++ appliance (the most energy efficient class) was 1186 EUR, whereas the average price for an A appliance was 459 EUR [10].
[9] www.topten.eu
[10] The washing machine mentioned has a loading capacity of 7kg.
[11] Incl. AT, BE, BG, CZ, DE, DK, ES, FI, FR, GB, GR, HU, IT, NL, PL, PT, RO, SE, SI, SK.
[12] This decrease might be due to the higher capacity.

Dishwashers

Also dishwashers have a lower penetration level than other major appliances (e.g. refrigerators and washing machines) in the EU-27. Penetration differs from country to country and is around 50-60% [9]. The most energy efficient product on the market with a place setting of 13 consumes 205 kWh/year and falls into the energy efficiency class A+++ (source: Website Topten International Group 2011)[13]. Between 2001 and 2005 there was only a relatively small efficiency progress in the dishwasher market. The efficiency improvements started to be visible after the year 2005 when the total consumption of the existing stock was estimated to be around 19 TWh in the EU-25.

Cooking appliances

Electricity consumption of cooking appliances is a substantial portion of total residential electricity consumption and there is still a significant energy saving potential for them.

The total electricity consumption for electric cooking was estimated to be around 60TWh (electric hobs and grills together) in 2007 [7]. The JRC estimates the consumption in 2009 to be slightly higher than in 2007.

In 2007, five years after the introduction of the energy label for electric ovens, more than 50% of new sales were made of A class appliances. The impact of the energy labelling is hence already visible on the market [7]. However a European Commission working document on possible energy labelling requirements for domestic electric and gas ovens and electric mains-operated range hoods has been produced in 2013 and proposed new energy efficiency classes (from A+++ to D) for electric and gas ovens.

Space and water heaters

Space heating equipment is the single largest electricity end-user in the residential sector and caused an electricity consumption of 150 TWh in 2007, this including electrical equipment (electric boilers and radiators) and monitoring and control equipment of other heating equipment fuelled by gas or oil [7]. Electric water heaters accounted instead for 8.7% of total electricity consumption corresponding to 73 TWh consumed in 2009. The energy consumption due to single electric space and water heaters is generally decreasing due to their competition with gas boilers and heat pumps and their consequent energy efficiency improvements. Nevertheless their overall electricity consumption has not changed in the period 2007-2009 probably also because of the increased per capita dwelling size observed in the recent years. Concerning water heaters, it is worth mentioning that the solar thermal heating systems have had an impressive development on the EU-27 market in the last years with much of the market made in one and two family houses. The solar thermal market in the EU-27 had in general a strong performance in 2008, growing by 60% and allowing achieving an overall installed capacity around 18.97 GWth in EU-27 ([7], [11]). Between 2009 and 2011, the EU market experienced an overall decrease in Europe but still remained above its 2007 level [12].

Residential room air conditioners

The European market for air-conditioning is still relatively young and still growing substantially. Summer periods represent more than 80% of the total yearly market volume for most of the regions [13] and weather conditions during these periods have a strong influence on the related market trends. In 2007 the overall electricity consumption of the EU-27 air-conditioning stock was around 17 TWh for both the residential and the tertiary sector. Low market growth rates were registered during between 2008 and 2009 because of the particular weather conditions. The air-conditioning stock and the overall electricity consumption is hence estimated to have remained almost constant until 2009. The biggest EU markets are Italy, Greece, Spain, and Southern France. More than three quarters of total EU sales for residential use were realised in these countries in 2005 (cooling capacity) [7]. The current energy label still leaves room for important improvements in energy efficiency, especially for split products. This market is indeed characterized by a so-called "impulse buying" caused by warm temperatures and inducing people to buy low price and inefficient models not mounting any inverter technology. Nevertheless, a quite recent GfK market survey shows that the sales of class A residential room air-conditioners increased from 41% to 57% across Europe between 2007 and 2010.

[13] More information can be found under: http://www.topten.eu/

Lighting

Lighting represents around 10% of the residential electricity consumption, being the third main consumer after heating and food refrigeration. Electricity consumption of households lighting was estimated to be around 84 TWh in 2007. Since then the consumption decreased substantially compared to other appliances groups resulting in an estimated electricity consumption around 79.8 TWh in 2009. This trend is expected to continue in the coming years.

Compact fluorescent lamps (CFLs) represent one of the most efficient solutions available today for improving energy efficiency in residential lighting. The recent price drop together with several information and promotion campaigns have had a positive impact on sales. The observed price reduction has been triggered mainly by the EU ban on incandescent completed in Sept 2012. An eco-design preparatory study of the European Commission [14] estimates a growth of CFL sales around 340% between 2003 and 2007. These estimates include however both domestic and non-domestic sales. This increase in CFL penetration was strongly stimulated in many Member States with special national policies and measures like the white certificates schemes implemented in Italy and the energy supplier obligations implemented the United Kingdom.

LEDs are an even more promising emerging technology and fall under the energy efficiency class A of the existing labelling scheme [7]. LED lighting starts to penetrate the market for replacement lamps, and special purpose lighting, although the market price for LEDs was still very high and their market penetration rate was still very low in 2011.

Class C halogen clear lamps (xenon-filled) will remain on the market until 2016. Starting from this year the dominant clear lamps will be the class B low voltage halogen lamps, with integrated or non-integrated transformer, unless new technologies will emerge.

Information and Communication Technology

Information and communication technologies (ICTs) are among the fastest growing electricity end-use in the residential and tertiary sector. The market is expected to continue growing. The size of the digital technology sector in Europe represents 4.5 % of EU aggregate GDP and even more if value added of digital technologies in other sectors is also accounted for [15]. Televisions (analogue and digital services), set-top boxes, broadband communication equipment, personal computers, computer monitors, imaging equipment, and external power supplies/ battery chargers are among the main product categories that fall under the ICT category or that cause electricity consumption because of the installation of products falling under this category.

The most important trends concerning the market of televisions relates to bigger screen sizes, flat panel displays, digital television broadcasting and high-resolution television (HD).

In 2007, the estimated electricity consumption of televisions in Europe was around 54 TWh. Despite an increase in energy efficiency, the total consumption of TV sets has been raising over the last years. This consumption increased by 2-3% between 2007 and 2009 and reached 56 TWh in 2009.

The increasing of the viewing time per person is accompanying the increase in sales of TVs in the EU. On average, people in the EU watched televisions for 225 minutes per day in 2007. Two years later the average viewing time per person reached 231 minutes [16].

The electricity consumption of TVs in the EU-27 in 2007 is estimated around 60 TWh, 54 TWh of which are generated in on-mode and 6 TWh in stand-by/off-mode. These figures are expected to have remained almost constant in 2009. The increase in the number of models installed per household, the fact that the old TV sets are often kept in the households, and the increase in viewing-time are working against the efficiency improvements.

The energy consumption of TV sets depends heavily on the screen size. The bigger the screen size the bigger the energy consumption. In the years between 2006 and 2010 the average energy consumption per TV set decreased for all screens of a same size. However, there are still large differences in consumption between different TV display types[14].

Digital TV, in the form of digital cable, satellite, digital terrestrial (DTT), and IPTV (Internet Protocol Television), is fast replacing analogue technologies. The adoption of digital television in Europe should grow strongly over the next years, providing enhanced image quality and advanced features (greater breadth of content and bundled communications). Apart from this enhancement, the switch-off of analogue transmission is a further key driver for the transition to digital TV in the EU [7].

During the on-going transition from analogue to digital broadcasting, TV sets not adapted to receive digital signals will need to be accompanied by simple set-top boxes (SSTBs) having the primary

[14] Plasma screens for example consume at least 35% more than LCD screens per screen unit area and tend to be larger than LCD screens (see 4E Mapping and Benchmarking report as available at http://mappingandbenchmarking.iea-4e.org/).

function of converting digital input into analogue output signals. Taking into account the fast penetration of digital TV sets on the EU markets, it is expected that in the next years the SSTBs will lose importance in favour of the complex SSTBs including additional features like pay-TV and network connectivity [7].
The annual energy consumption of SSTBs is estimated at 6 TWh in 2010 and 14 TWh in 2014 (without any minimum efficiency standards) [17].

Broad Band Communication equipment
Broadband equipment is becoming an important electricity end-user in the residential sector and associated electricity consumption in the standby status is also becoming relevant. It is estimated to consume up to 50 TWh/year by 2015 in the EU-27. Its market penetration increased from 4.9% in 2004 to 25.6% in 2010 and continues to grow. DSL is the main technology in the EU fixed broad band market (77.5%), although its market share in the new connections was decreasing in 2010 compared to the year before. The highest growth took place in the mobile broadband market (dedicated data service cards/modems/keys) which grew by 30% in the period between July 2009 and July 2010.

Personal computers, computer monitors and imaging equipment
Computers have become ubiquitous and numbers representing their penetration in the household sectors are impressive. In 2010 their penetration has been above 80% in DE, DK, LU, NL, SE, FI, UK, above 70% in AT, BE, FR, IE, MA, SI, SK and below 50% only in RO and BG where it was anyhow over 30%. Practically all houses where a computer is installed have an internet access [18]. In order to grasp the impact of computer technologies and office equipment in general on the EU-27 electricity bill, it may be useful to consider that the electricity consumption due to this equipment has been around 50 TWh in 2010 (source Energy star programme in 2006-2010 and [19]). It has been estimated that without the EU Energy Star programme on voluntary energy labelling for office equipment this consumption will have been 20% higher in 2010 and 30% higher in 2020. Electricity consumption due to computers, displays and imaging equipment is expected to achieve 55 TWh in 2020.

External power supplies/battery chargers
Electricity consumption to be attributed to external power supplies (EPS) not including the electricity consumption of primary load products, was estimated to be around 17 TWh/year in 2009 [21]. According to [7], EPS for notebooks, set top boxes, mobile phones, DECT (digital enhanced cordless telecommunication) and printers represent respectively 32%, 11%, 23%, 15% and 13% of the above mentioned total electricity consumption. This consumption will be destined to increase in the next years especially due to the increase of ICT equipment installed.

Stand-by and off-mode losses
Standby functions and off-mode losses are a common feature of electrical and electronic household and office equipment (consumer electronics, information and communication technology equipment, personal care products, etc.). The users are often not aware of the electricity consumption and costs for stand-by/off-mode (small for a single product) and low power consumption in stand-by/off-mode is not an important purchasing criterion. Taking into consideration that a typical household is in general equipped with dozens of products having stand-by/off-mode, the resulting electricity consumption and the associated costs are significant. The technical solutions reducing energy consumption in stand-by/off-mode are frequently not applied, for example due to possible additional costs for the manufacturer, and also because it is not a market access requirement ([20], [7]).
Available statistics indicate that the total standby electricity consumption of home appliances in EU-27 in 2007 amounted to around 43TWh, representing 5.4% of total residential electricity consumption in this year [7]. According to a more recent study based on measurements in 1300 homes across the EU, the average standby electricity consumption is about 305 kWh per household per year, representing about 11% of the total annual electricity consumption per household [5]. Horizontal standby policy measures like those implemented in the EU represent probably the best approach to counteract the increase of standby and off-mode electricity consumption due to the constant proliferation and evolution of electrical and electronic equipment.

Summary on electricity consumption trends for the main residential energy end-uses

As showed by the data provided in the previous paper sections, the general trend for residential sector is an increase in its electricity consumption. Although many appliances are becoming more efficient, the number of installed appliances is raising, appliances are used more often or for longer periods of time, and many appliances have more functions or special features that require more energy.

For white appliances the case of washing machines is for example remarkable. Despite a significant increase in the energy efficiency of the models commercialized, the increase in the number of washing cycles and loading capacities seem to have caused an increase of the overall electricity consumption to be attributed to these appliances[15]. Tumble driers and air conditioners are other domestic appliances whose impact on the European electricity bill could rise despite important improvements in their energy performances. In this case this might happen because of an increased market penetration of these products caused by a change in building practices and in practices or regulations concerning how people dry their clothes or create good comfort conditions in their houses.

The evolution of the overall impact of space and water heaters on the EU electricity bill is being instead affected by different and counteracting trends. These trends are the increasing energy performances of these appliances, the increasing per capita dwelling size observed at least in the recent years, the possible push for a fuel-switching from gas to electricity caused by the increased penetration of renewable energy sources for electricity, the increased installation of solar thermal water heating systems.

An important contribution to increased EU residential electricity consumption comes finally from the ICT equipment. Televisions (analogue and digital services), set-top boxes, broadband communication equipment, personal computers, computer monitors, imaging equipment, and associated external power supplies/battery chargers and standby consumption represent together at least the second source of electricity consumption in the households and their increasing impact on the household electricity bills appears difficult to be counteracted despite the significant energy efficiency improvements registered.

There are, however, also end-uses whose overall energy impact is decreasing with time at the EU level. This is the case, for instance, of electricity consumption due to residential lighting. The decreased electricity consumption of residential lighting is to a large extent the result of the phasing-out of less energy efficient incandescent light bulbs caused by EU regulations. Also the large promotion of CFLs in many EU Member States, even before the incandescent lamp phase out period concluded in 2012, contributed to this success. Overall, EU policy instruments have in general the fundamental merit of having significantly reduced or at least increased awareness concerning the overall impact of practically all household appliances nowadays installed. The next paper section will be dedicated to a short overview of these instruments.

EU legislation on household appliances and related impacts on electricity consumption

Energy efficiency legislation of household appliances implemented at the EU level focuses on two main approaches: labelling and standard product information and minimum energy performance standards (eco-design). In the last four years two important directives concerning energy efficiency have been published: directive 2010/30/EU on labelling (*directive on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products*) and directive 2009/125/EC on eco-design (*directive establishing a framework for the setting of ecodesign requirements for energy-related products*). Both directives are new versions of already existing directives (directive 92/75/EEC for labelling and directive 2005/32/EC *establishing a framework for the setting of eco-design requirements for energy-using products).*

A list of measures implemented or in course of implementation under these two framework directives is provided in Table 1 below.

[15] It seems unlikely that the observed increase in the energy consumption can be attributed to any kind of direct or indirect rebound effect of the energy efficiency improvements registered in this sector.

Table 1: Measures implemented or in course of implementation under Directive 2009/125/EC on eco-design and Directive 2005/32/EC on energy labelling.

Product group	EcoDesign Measure Implemented
Dishwashers	YES
Washing Machines	YES
Air-conditioning	YES
Space and Combination Heaters	NOT YET
Water Heaters	NOT YET
Computers and Servers	NOT YET
Directional Lighting	NOT YET
Domestic Lighting	YES
External Power Supplies	YES
Laundry driers	YES
Ovens, hobs and grills	NOT YET
Refrigerators and Freezers	YES
Residential ventilation	NOT YET
Simple Set-Top Boxes	YES
Complex Set-Top Boxes	YES (VA*)
Standby and Off Mode	YES
Televisions	YES
Imaging equipment	YES (VA*)

Product group	Energy label implemented
Cold appliances	YES
Washing machines, dryers and their combinations	YES
Dishwashers	YES
Ovens	YES
Heat and water heaters	NOT YET
Lighting sources	YES
Air conditioning	YES

* VA = Voluntary agreement

The impact of the above measures on the electricity consumption of the products addressed is expected to be extremely relevant as indicated, for example, in the existing estimates concerning the annual energy savings that will be achieved in 2020 thanks to the eco-design requirements so far established (see Table 2 below). Moreover existing analyses of their cost effectiveness for the European Commission and the Member States indicate a potentially very high benefit to cost ratio [2].

Table 2: Estimated energy savings for eco-design regulations implemented in the residential sector[16]

Adopted implementing measures	Estimated savings (annual savings by 2020) in TWh
Standby and off mode losses of electrical and electronic equipment (household and office)	35
Simple set top boxes	6
Domestic lighting	39
External power supplies	9
Televisions	28
Circulators	23
Domestic refrigeration	4
Domestic dishwashers	2
Domestic washing machines	1.5
Air conditioners and comfort fans	11

Unfortunately the situation of general scarcity of market data does not allow performing precise evaluations on the electricity savings so far achieved because of the implementation of the above listed measures.

However, despite this data scarcity, despite several measures implementing eco-design requirements have been introduced very recently and despite their most stringent requirements (e.g.Tier-2 requirements) have not yet entered into force, evidences of the their positive impacts on residential electricity consumption already start to be available. Independent assessments of the impacts so far achieved by the eco-design regulations ([2], [3]) have indeed confirmed a positive and direct impact on energy efficiency of domestic lighting and an indirect role in the improvement in relation to standby and off modes. In the case of televisions, cold appliances, washing machines and dishwashers, existing evidences do not yet seem to allow to directly link the important market developments in the direction of a higher efficiency to the eco-design regulations addressing these products, although these studies admit that the regulations may have contributed to amplify existing improvement trends. No data are instead yet available to assess the impact of measures on battery charges and simple set-top boxes.

Concerning market impacts, no evidence on possible negative impacts of the regulations on the price of energy related products has been gathered and it is generally recognized that these regulations have not introduced excessive additional costs for the industry (although these costs may clearly represent a higher burden for SMEs than for larger industries). Moreover market operation does not seem to have been affected by adverse effects due to the regulations and a positive impact on technology innovation is widely acknowledged.

On the procedural, side some points of improvement have been identified, especially concerning the length of the procedures for the development of the implementing measures. It has been estimated that the time needed to implement a regulation from the starting of the preparatory studies to its publication is typically 4 years and often it tends to stretch out to 6 years [2]. Such a long implementation time is typically attributed to the scarcity of human resources available in the European Commission and may cause that requirements adopted are less stringent than expected

[16]Source:http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/ Some of the measures listed (e.g. external power supplies, standby and off mode losses, air conditioners and comfort fans) do not concern exclusively products installed in the residential sector.

because they are based on market data which may be outdated. For example, it has been pointed out that delays occurred in the development of the eco-design regulations for space and water heaters and for televisions may have caused the missing of an opportunity to realise much more energy savings [2], [3]. Synchronization between the development of implementing measures and the development of harmonised standards needed for the measurement of the energy performance parameters mentioned in the regulations is another important point of attention. Harmonised standards have indeed to be in line with the assumptions adopted in the EU Commission preparatory studies for the estimation of the energy performances of products and in the regulations for the definition of the parameters and the formulas whereby energy performance requirements and threshold values for possible energy efficiency indexes are established. If this is not the case, it may happen that the effects of the regulations result very different form the expected ones. It is for this reason that final harmonised standards should be developed *only once* at least a draft of the regulation requiring their application has been produced by the European Commission based on a as wide as possible consensus among all concerned stakeholders on the assumptions and the parameters considered in the regulation. On the other hand, measurement and testing methods adopted in the harmonised standards should not differ significantly (in terms of resulting energy consumption of products) from those assumed in the preparatory studies. Otherwise the consequent revision of these studies and of the analyses leading to the formulas and the requirements included in the regulations might cause a delay in their implementation.

Market surveillance and regulation enforcement at the national level represent a further important point of attention, as it is widely believed that sufficient resources for effective monitoring and enforcement are not allocated at this level.

A final point of attention relates to the co-ordination of existing EU sustainable product policies (i.e. EU policies concerning energy labelling, eco-label, green public procurement and eco-design). Although eco-design regulations are effectively linked with the EU labelling scheme, the EU Commission is working at possibly improving their co-ordination with the green public procurement (GPP) and the EU eco-label schemes in order to better integrate and streamline the implementation process of these policies.

Conclusions

The residential sector is the second consumer of electricity coming after the industry sector in the EU 27. Its electricity consumption grew by about 40% between 1990 and 2010 achieving 843 TWh (i.e. 30% of the total EU electricity consumption) in 2010. This consumption increased almost constantly during these two decades.

Space and water heating systems consume all together 28% of the final electricity used by EU households. They are the first electricity consumer in the EU and are followed by information and communication technologies in the electricity consumption ranking of domestic appliances. Important improvements in the energy efficiency of all domestic appliances sold on the EU market have been achieved and are responsible for the lower annual average electricity consumption grow rates being registered. The merit for this goes to policy induced and spontaneous technological improvements that have taken place in the domestic sector.

As far as EU policies fostering energy efficiency improvements are concerned, energy efficiency policy measures have been implemented at the EU level for practically all appliances used by households. Eco-design regulations for these products are expected in particular to allow achieving further and significant amounts of energy savings by 2020. Available data are however generally not sufficient to evaluate the overall impact on electricity consumption they have had until today. This difficulty is also partly due to the fact that several eco-design regulations have been implemented very recently and that their most stringent requirements have not yet entered into force. Nevertheless some evidences start to be available concerning a positive and direct impact had on energy efficiency of domestic lighting and an indirect role in the improvement in relation to standby and off modes.

Undoubtedly, it cannot be denied that improvements must be achieved in the field of data collection and data analysis in order to allow a proper monitoring and a better design and enforcement of the energy efficiency policies implemented. These improvements relate mainly to the following three areas:

a) standardization of test methods used to measure the energy consumption and other relevant energy related characteristics of the domestic appliance commercialized on the EU market;

b) availability of data and information concerning models put on the EU market for an independent evaluation of their energy performance and other relevant associated characteristics (e.g. models' sale price);

c) reliability of the reference consumption baselines used for the calculation of the energy performances of the products commercialized.

The proper realization of the activities to be accomplished under each of these areas require a strong and collective engagement of manufacturers who receive the highest benefit from their efforts to improve the energy performances of their products when independent (regulatory) bodies co-ordinate and support the standardization processes needed, provide suitable platforms for data collection while guaranteeing transparency and respecting possible data confidentiality issues, perform the analyses for the calculation of the expected energy efficiency improvements expected or achieved in the market. Although a huge amount of work has been and is still being carried out by all the actors involved, the amount and the quality of data available and the resources employed in the above areas do not always allow to exploit an important part of the economic and energy saving potentials associated to energy efficiency. Recent actions undertaken by the European Commission to achieve improvements under these areas are described in its communication COM(2012) 765 and include an increase in the level of involvement of other EU bodies (e.g. the Joint Research Centre), external experts and NGOs in the the standardization work concerning the measurement of products' energy consumption as well as the creation of a database on the energy efficiency and on other environmental aspects of products placed on the EU market. Another useful action not mentioned in the communication that could facilitate data collection and market surveillance activities would be the requirement for on-line registration of all new models put on the EU market by manufacturers.

Concerning the energy efficiency policy implementation process and the nature of the measures put in place at the EU level, the following three remarks can be formulated:
a) one area of improvement concerns the usually too long duration of the time period passing from the starting of the preparatory studies needed for the definition of the implementing measures to the actual implementation of these measures. There is also a need for a better synchronization between the processes leading to the definition of the implementing measures and the definition of the harmonized standards necessary for product performance measurement. Moreover an improved co-ordination and a more streamlined and integrated approach in the implementation of existing EU sustainable product policies (i.e. EU policies concerning energy labelling, eco-label, green public procurement and eco-design) has to be achieved. It is however worth mentioning that in 2012 the EU Commission started a pilot project carried out by the main directorates involved in the implementation of the sustainable product policies (DG ENER, DG ENTR, DG ENV) and by the Joint Research Centre in order to address these issues.
b) Market surveillance activities and EU regulation enforcement at the national level is another important area of improvement. In this case the contribution of the EU MSs is fundamental in order to ensure that market surveillance is properly realized, whereas the rules to be applied have to be defined at the EU level. In order to provide support on market surveillance, the EU Commission has launched an annual market surveillance data collection exercise and promoted a joint action on market surveillance among national authorities under the Intelligent Energy Europe (IEE) Work Programme 2013 to enhance the enforcement of the Ecodesign and Energy labelling legislation.
c) The trends observed in the evolution of electricity consumption of domestic appliances indicate that the improvement registered in the energy efficiency of products is not always accompanied by a reduction of the total electricity consumption these products generate in the households. As already mentioned in this paper, this may happen because of additional services attached to products (e.g. larger sizes, additional functionalities), more intensive usage, multiplication of same product types in the households (e.g. televisions, refrigerators), etc. This issue represents probably the main challenge of current policies and according to some experts it puts under question the actual effectiveness of energy efficiency policies as a whole. Finding solutions to face it is of paramount importance especially when it is taken into account that the shift towards renewable energies that is taking place in the EU seems to be destined to determine a fuel-switch towards electricity for many domestic and not domestic energy end-uses and that this switch will very likely make the problem of limiting total households electricity consumption even more important. Solutions so far proposed to address the problem basically propose to design policies promoting energy efficiency and simultaneously limiting total consumption growth. According to some experts this could be achieved by combining energy efficiency policies with policies aiming at increasing energy prices. According to others energy efficiency policies should instead be accompanied by measures limiting energy consumption growth directly (e.g. by establishing volume limits for refrigerators commercialized, by increasing the price of bits/sec. transmitted by communication technologies, etc.). Both approaches, however, can become questionable for different reasons. Whereas the former approach may raise social equity issues

connected to any energy price increase, the latter is often perceived as a limitation of individual freedom. A shift of paradigm is probably requested in this case and requires that mechanisms whereby human needs and wants related to energy end-use technologies are socially constructed are better understood and possibly modified through policy action. Unfortunately sociological studies do not have so far gained the attention they deserve in the energy policy field.

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Trends in Residential Electricity Use and Other Lesson from Data Analysis

Virve Rouhiainen

Adato Energia Oy

Abstract

The paper analyses the trends in residential electricity use in Finland on basis of three cross section studies (1993, 2006 and 2011). In 2011 appliances stood for 41 % of the electricity consumption of household, sauna stoves and HVAC appliances for 9 %. The rest is electric space and domestic hot water heating. Between 2006 and 2011 electricity consumption in households increased by more than two terawatt hours (TWh) and is now close to 20 TWh. The increase is due entirely to the increase in electricity consumption associated with the heating of homes. A number of factors contribute to this development. The most important are increased number of heat pumps, increased secondary electric heat and increased mechanical ventilation and heat recovery. Adoption of energy efficient technologies in heating increases the use of electricity because the heating energy saved is other than electricity.

The electricity consumption of household appliances in 2011 was on the same level as in 2006, because the reduction in consumption in lighting and TV appliances offset the increased electricity consumption of computers, dishwashers and car heating. In appliances the most important trends are: electricity consumption of televisions is decreasing (reduced standby dominates), electricity consumption of computers (including internet connection) is increasing (volume effect dominates), lighting consumption is decreasing.

Number of smaller lessons can be drawn from the data analysis. These include a need to improve customer information on heating and ventilation especially in the segment flats, need to investigate further the actual performance of heat pumps in the field and effect of technology and price incentives on water usage patterns. Further prebound effect may be present in Finland.

Introduction

The Finnish Household Electricity Use Studies comprise three studies on the years 1993 [1], 2006 [2] and 2011 [3]. This paper describes the trends in residential electricity use in Finland on basis of these studies.

The paper is structured as follows. First, the studies and the used methodology and data are outlined briefly. Then the results are presented and discussed.

The results are: the country (area) level decomposition of electricity consumption to end-use categories, construction of example households used in customer communication and the distribution of consumption for the 40 reference groups for the user reports the Finnish electric utilities are required to send their customers. The two first ones are described in the paper in detail. The third result was introduced in 2010 and it is illustrated by appending the model report for time of use tariff. The comparison tables of this report show how electricity use varies between customer groups and are based on 2006 data.

One should note that the paper is highly descriptive in nature. The statistical methodology is only outlined, not discussed in detail in theoretical context. The need for these results is taken for granted and so the usefulness of this kind of description is not discussed. The focus of the paper is presenting the results.

Methodology

Figure 1 describes the types of data used to derive models and the three types of results of the study. The ellipses describe data. The studies use three or four types of data: purpose tailored survey combined with total measured electricity consumptions, measurements in the survey sample (optional), population data from Statistics Finland and data collected from other sources like laboratory measurements for energy labels.

The 2011 study used survey data on app. 4500 households. For 2006 the sample size was over 3000 observations and for 1993 over 2000. In the first two studies measurements were carried out in approximately 100 households. Number of measured appliances was app. 700 in 1993 and 950 in 2006

The first line of boxes describes analysis needed for generalization and model building and the second line of boxes describes model testing. The third line shows how these steps in the analysis are combined to derive results. Next these steps will be described briefly. A reader unfamiliar with statistical modeling and testing may wish to skip the formulas in the next three paragraphs. More detailed description of this part can be found in EEDAL09 proceedings [4].

The first stage of building the appliance models for survey data is to calculate unit consumption for all the major appliances in all of the surveyed households. As the 2011 study only used survey data, the model specified with the help of auxiliary data, was statistically tested and modified till the test indicated that the model was correctly specified.[1]

The test used was a variation of a standard test for testing restrictions set for parameters in linear regression models. In modeling the total electricity consumption y_i of each household i in the survey was decomposed on basis of the questionnaire data to end-uses EU_j and an error term ε_i, shown as formula (1).

(1) $$y_i = \sum_{j=1}^{k} EU_j + \varepsilon_i$$

This is then written in form of a linear regression by adding the regression coefficients β_j for all the end uses i.e.

(2) $$y_i = \beta_j \sum_{j=1}^{k} EU_j + \varepsilon_i$$

If the model is correctly specified, $\beta_j = 1$ for all j. To test the hypothesis of correct specification one estimates both the restricted and unrestricted model. The test statistic F constructed from the error sum of squares is

(3) $$F = \frac{(SSE_r - SSE_f)/(p-q)}{SSE_f/(n-p)} \approx F((p-q),(n-p)$$

The formulation above applies for homoscedastic error term, when in practice the error term is heteroscedastic. To allow for heteroscedastic errors one can use weighted least squares and replace SSE with weighted residuals to get an appropriate F-test. Another alternative is to use likelihood ratio tests, which also allow for testing non-linear restrictions. This is needed when testing heating models where additive structure of end-uses is no longer sufficient.

The analysis of representativeness and determination of weights is an extremely important part of the analysis. Of the random sample drawn, only 34 % responded, so the results are subject to non-response bias. The analysis revealed a picture similar to that of earlier studies: larger households, households in single family houses and houses with electric heat were clearly overrepresented. The weights were determined on basis of the analysis auxiliary population data and the model results were then weighted on population level via post stratification.

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[1] In technical terms this means that H_0 hypothesis of correct model specification would not be rejected at 5 % confidence level.

Figures 2 and 3 illustrate[2] the effect of weighing with 2006 data. The data is divided into five strata which are weighted so that size of each stratum corresponds to its share of the dwellings in Finland[3].

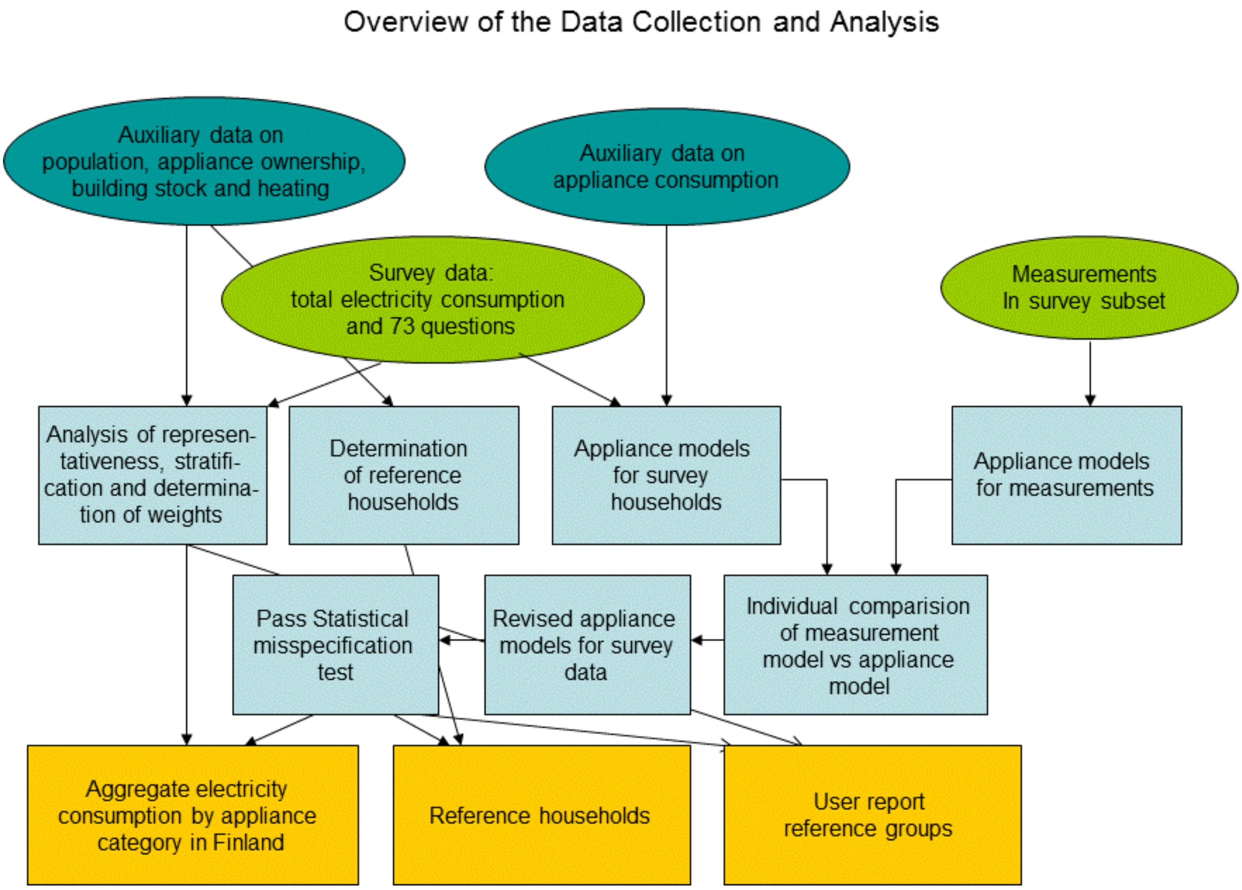

Figure 1. Overview of the Data Collection and Analysis

It is easy to see that the weighing changes the form of the histogram (or empirical distribution) considerably. The spike at 2000 kWh's is much clearer and the right tail considerably flatter in the weighted distribution than in the non-weighted distribution. Without weighting the estimate derived from the data for the total consumption of residential electricity in these segments is 25 % higher than actual known number. The propensity to answer is higher the higher the electricity consumption of the household. This makes the sample biased. Weighting is used to correct this bias.

The definition of strata depends on the available population data and expected differences between the strata. The five segments in figures 2 and 3 are clearly different. First explanatory factor is whether the home is electrically heated or not. In Finland approximately two thirds of residential energy consumption is space heating [4], so this component, when electricity, is large. However, practically no apartment block in Finland is electrically heated. The dominant heating form is central heating with district heat. In addition, in apartment blocks the electricity used by the heating system, car heating, common saunas and hallway and garden lighting is billed from the housing company and paid by the households as a part of a maintenance fee. Similar arrangement is typical in three out of

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[2] The word illustrate is used because the number of strata in the actual weighting was 35, not 5.

[3] This data is based on population and building register and the data on number of occupied and unoccupied dwellings and number of occupants is highly accurate. There's more uncertainty with main heating energy source, because change of heating energy source is not always registered. Statistics Finland is now working to improve this information,

four row houses. Approximately 25 % of the dwellings in row houses use direct electric heat and residents pay for their heating in their electricity bill. In contrast, a resident of single family house is billed for all residential energy by the energy company[4].

This means that electricity companies bill residential energy including electricity from housing companies. In electricity this component amounts to approximately to 2 TWh at country level [4]. This electricity is not covered by this study, though it is included in the official residential energy statistics of Finland. Same applies to holiday residences, second homes and vacant dwellings. Finland has app. 280 000 dwellings without permanent residents. That is 10 % of the dwelling stock. These include both second homes and vacant dwellings. In addition, Finland has app. 500 000 holiday homes.

The sampling frame in 2011 covered these, but only 2 % of answers belonged to these strata. This data set was not large enough for any meaningful generalization, so the results presented here describe electricity use of permanently occupied dwellings excluding electricity paid by the housing companies.

Results

Results at Country Level

Table 1 shows how the total electricity consumption of permanently inhabited dwellings falls into three broad categories in 1993, 2006 and 2011. The first category is appliances and lighting, the second category is sauna stoves and heating and ventilation equipment and the third category is electric space heating and domestic hot water. These categories are further broken down in tables 2, 3 and 4 and the percentages calculated from the grand total.

Table 1. Electricity consumption of permanently inhabited dwellings in Finland 1993, 2006 and 2011.

End use category	1993 GWh	%	2006 GWh	%	2011 GWh	%
Appliances and lighting	6379	44 %	8201	46 %	7935	41 %
Sauna stoves and heating and ventilation equipment	1089	8 %	1473	8 %	1809	9 %
Electric space heating and domestic hot water	6894	48 %	7996	45 %	9493	49 %
Total	14362	100 %	17670	100 %	19237	100 %

Table 2 presents the electricity consumption of appliances and lighting in Finland by appliance category in 1993, 2006 and 2011. The classification of the earlier studies has been changed to correspond to the concepts used in the official statistics. The first thing to note is that the total of consumption by appliances and lighting decreased from 2006 to 2011 in absolute terms. The largest reduction is estimated in lighting by app. 900 GWh and the second largest in televisions by app. 270 GWh. Categories cooking, cold appliances and washing and drying laundry also show slightly reduced consumption. The computers show the largest increase in electricity consumption by app. 440 GWh. The second largest increase is found in car heating by app. 350 GWh and the third largest increase in dish washing by app.100 GWh.

[4] This is a simplification. A number of Finnish households use wood that they obtain from their own forests or receive from relatives. They, however, are aware of the fact.

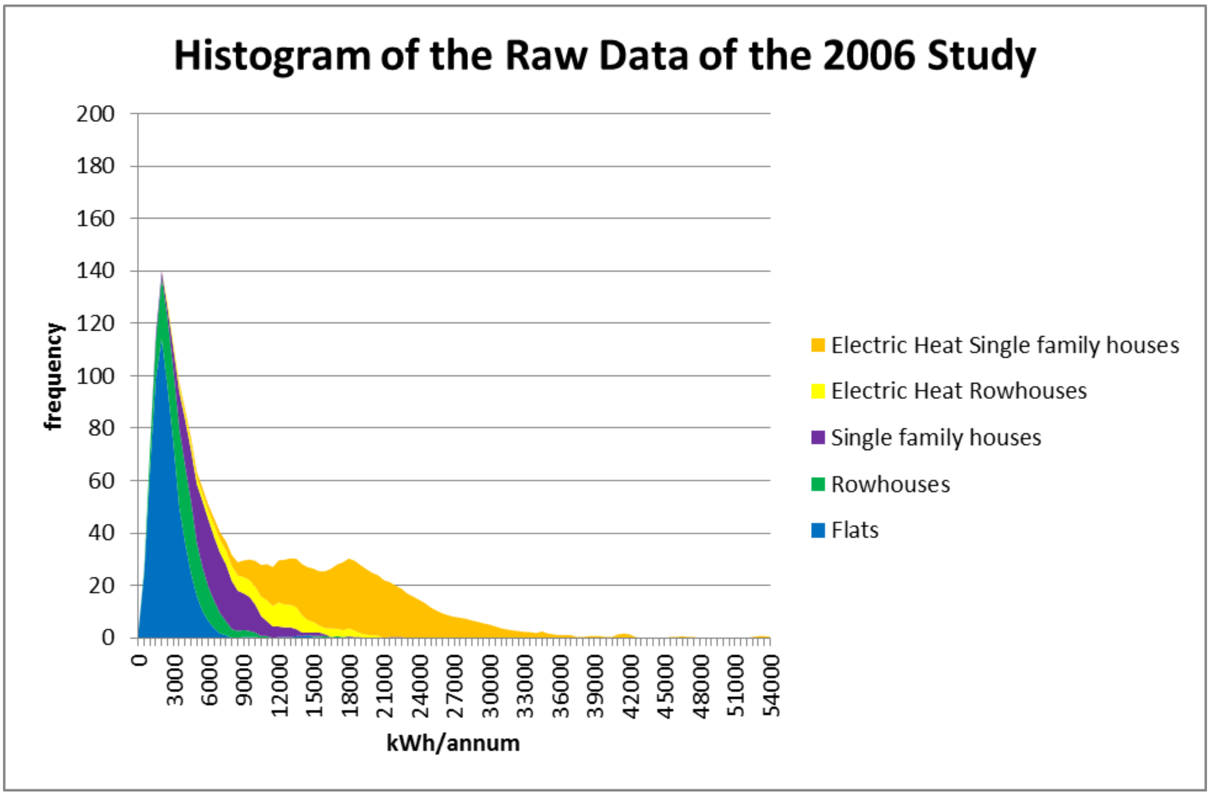

Figure 2. Histogram of the total electricity use by strata using the non-weighted data of the 2006 study.

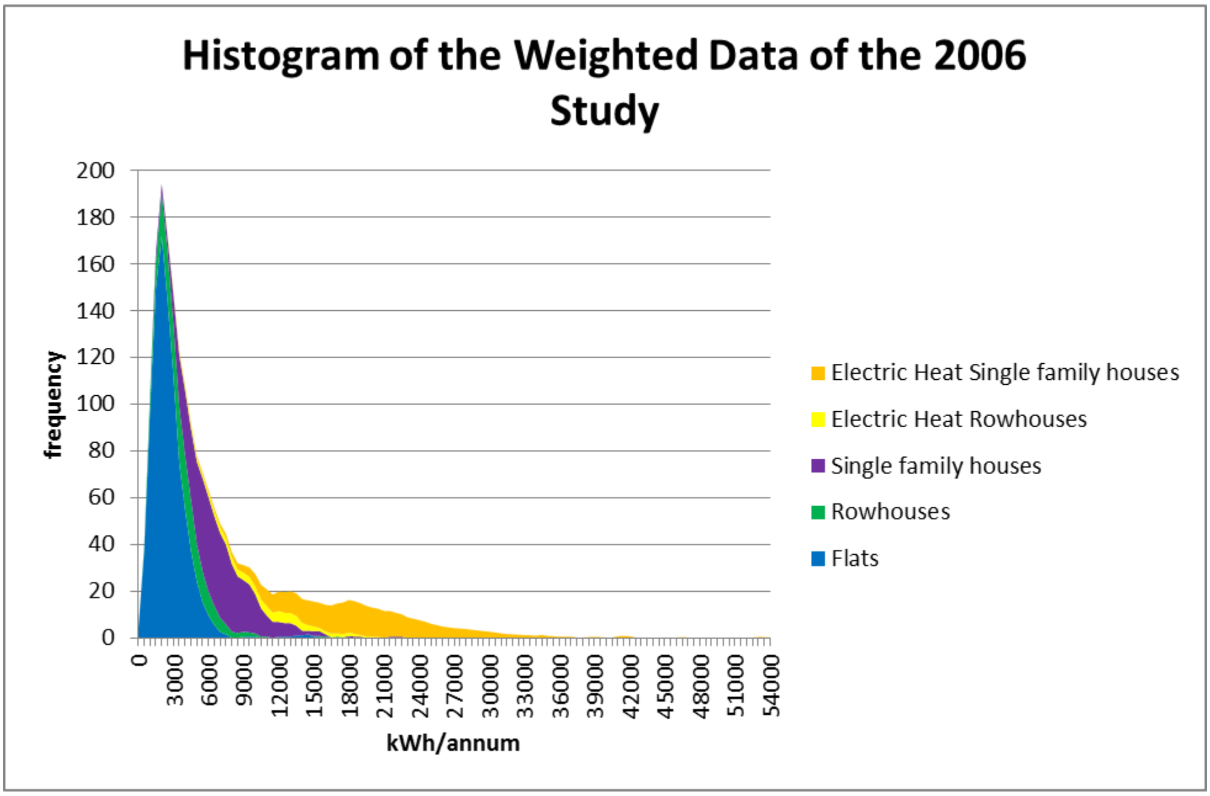

Figure 3. The histogram of the total electricity use by strata using the non-weighted data of the 2006 study.

Both in lighting and television the reduction results from increased energy efficiency. The number of TV's is no longer growing. During the years 2007-2010 over 1.7 million LCD televisions were sold [6], so that 70 % of the total television stock was renewed, the new appliances having stand by below 1 W and an inbuilt digital receiver. This resulted in large decrease energy consumption. The energy efficiency of computers also increased during 2007-2010. Today 63 % of computers are laptops compared to 40 % in 2006. In measurement studies the average laptop consumes 80-90 % less than an average desk top [2,7,8,9]. However, the number of computers and broad band connections are increasing at a very rapid pace. In 2006 40 % of Finnish households did not have a computer or a broadband connection, In 2011 this share was 15 % [10]. In 2006 a laptop was used on average 2 hours per week. In 2011 the average was 4. In 2006 the average desk tops usage was 4 hours a week, in 2011 the usage increased to 4,5 hours. Between 2006 and 2011 total share of computer increased from 123 % to 153 %, which means that second and third computer became increasingly common. This resulted in an overall increase in electricity consumption.

Table 3 shows the electricity consumption of heating and ventilation equipment and electric sauna stoves. Both categories show increase in absolute consumption as well as their share of the total consumption. The electricity consumption doubled from 1993 to 2011, yet it is worth noting that heating and ventilation represent just 8% of the overall dwellings consumption. Much from the increase is attributable to heating and ventilation equipment which are increasing in numbers and to an extent in intensity of use. Existing building regulations require use of mechanical ventilation with heat recovery.

Table 2. Electricity consumption of appliances and lighting in Finland in 1993, 2006 and 2011

	1993		**2006**		**2011**	
Appliance category	**GWh**	**%**	**GWh**	**%**	**GWh**	**%**
Cooking	796	6 %	653	4 %	632	3 %
Cold appliances	2 215	15 %	1 461	8 %	1410	7 %
Dish washing	125	1 %	261	1 %	367	2 %
Washing and drying laundry	316	2 %	391	2 %	373	2 %
Television and related appliances	537	4 %	834	5 %	564	3 %
PC's and related appliances	(-)		407	2 %	848	4 %
Car heating	226	2 %	218	1 %	571	3 %
Lighting	1 541	11 %	2 516	14 %	1520	8 %
Other equipment	623	8 %	1468	8 %	1649	9 %
Total	**6379**	**44 %**	**8201**	**46 %**	**7935**	**41 %**

Table 3. Electricity consumption of HVAC equipment and sauna stoves in Finland in 1993, 2006 and 2011

	1993		**2006**		**2011**	
Category	**GWh**	**%**	**GWh**	**%**	**GWh**	**%**
Heating and ventilation equipment	483	4 %	621	5 %	948	5 %
Electric sauna stoves	606	3 %	852	4%	861	4 %
Total	1089	8 %	1473	8 %	1809	9 %

Table 4. Electricity consumption of electric heating in Finland in 2006 and 2011

Electric heating category	2006 GWh	2006 %	2011 GWh	2011 %
Domestic Hot water				
Room heating	1242	7 %	1307	7 %
Central heating	250	1 %	520	3 %
Secondary electric heating of living space				
Floor heating (electric cable)	206	1 %	464	2 %
Heat pumps	50	0 %	142	1 %
Other	60	0 %	122	1 %
Hydronic central heating – heat pumps				
Ground heat pumps	125	1 %	287	1 %
Other heat pumps	60	0 %	79	0 %
Secondary electric heating living space	20	0 %	29	0 %
Traditional electric heat				
Room heating (dry)	4823	27 %	4562	24 %
Central heating	550	3 %	681	4 %
Secondary electric heating living space	400	2 %	485	3 %
Heating of annexes	209	1 %	303	2 %
Air conditioning	0	0 %	46	0 %
Total	**7996**	**45 %**	**9493**	**49 %**

Electric heating in table 4 is divided into three categories. These are non-electrically heated homes, hydronic heat pump systems, and traditional electric heating. In addition, electric heating of ancillary buildings and outdoors, air-conditioning and hot domestic water each form a category.

Electricity is used in non-electrically heated homes to provide alternative or additional heating. Non-electrically heated homes include all centrally heated dwellings in apartment blocks and row houses irrespective of heat sources and single family dwellings with central heating using district heating, oil or wood or pellet as a heat source. Additional heating is sometimes called comfort heating as the most common form is floor heating in bathroom.

Secondary electric heating of living space is divided into three groups: floor heating (electric cable), heat pumps and other additional electric heating. The increase in floor heating is of the same magnitude as the decrease in the consumption of televisions and it can be seen in all dwelling types. Heat pumps in this category are usually air-to-air heat pumps mostly found in single family houses with central oil fired heating. 22 % of these houses have an air-to-air heat pump used for heating. Other additional electric heating includes electric radiators and similar items. They are seldom used in centrally heated dwellings unless part of dwelling is without central heating.

Hydronic central heating with heat pumps includes ground source heat pumps, the air-to-water heat pumps and part of the exhaust air heat pumps. As the figures show a ground source heat pumps dominate this group. Geothermal energy is used for space heating in nearly 6% of the Finnish single family houses [11] and this share is increasing rapidly. The group secondary electric heating covers floor heating with electronic cable, air source heat pumps and separate electric radiators.

The traditional electric heating is divided into two categories dry systems and water based systems. In both groups heat pumps are becoming increasingly common. In 2011 approximately 40 % of the electrically heated single family houses also used heat pump. But that is not the only additional heat source, namely 75 % of these households use wood in heating as well. Figure 4 shows how this is reflected in electricity use.

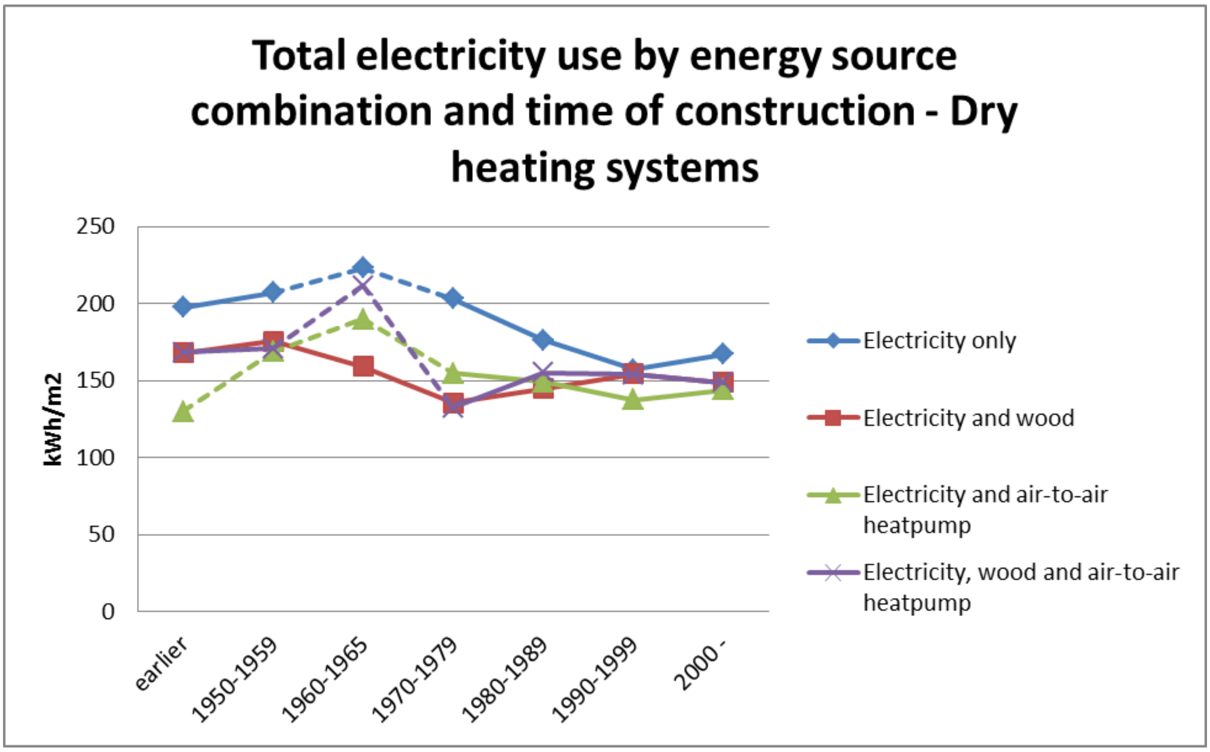

Figure 4. Total electricity use per square meter by heating energy source combination and time of construction, single family houses with dry heating system.

Reference households

The reference households are used as a communication tool, the most important target group being household customers. Most customers are interested in their electricity bill, thus the reference households are defined so, that they cover the variation in electricity use and analysis is limited to the electric energy paid directly by the consumer. Figure 7 shows the total consumption and its development in time for each reference household defined in the three studies. Note that the number of reference households has been increasing. The 2011 study included electric heating so two new reference households were defined. In 2006 study, four new households were defined and one definition from 1993 was revised.

The upper level definition is based on dwelling type (flat, row house, single family house) and number of inhabitants. The equipment stock and level use is determined from the data using set principles:

1. If 50 % or more of the household type in questions owns an appliance then it belongs to the equipment stock of the typically equipped reference household.

2. If app. 10 % of the household type in questions owns an appliance then it belongs to the equipment stock of the highly equipped reference household.

3. In both groups the amount of use of the appliances corresponds to median. The reason for this is for skew distributions that median is better suited for comparison as 50 % of the observations are below and 50 % of them are above median.

Basing the definition of the reference household on data defined statistics also facilitates comparison over time. Though this typically is not necessary in customer communication, it helps explaining the development of the aggregate figures.

Figure 1 shows the numbers for a single in flat and figure 2 for a family of four in a detached house. In these examples district heat is used as heating energy, though for different reasons. In flats this reflects reality – 90 % of Finnish flats use district heating. In 2011 only 7 % of the detached houses used district heat, in central heating the most common energy source was fuel oil. The analysis of data, however, revealed that what was typical for fuel oil was atypical for district heat. Namely, the combined share of electric floor heating and air-to-air heat pump in house using fuel oil as main heating energy was over 50 % and thus secondary electric heating would be part of a typical appliance stock in these houses. Though adding up 30 % of the typical consumption of the floor heating and 20 % of the typical consumption of air-to-air heat pump would result in a plausible figure for floor heating, the adoption of verbal description of the situation was preferred to incorporating this kind of calculation into the example.

This development has more general bearing. As time passes by the appliances that once belonged to the highly equipped house become part of a typically equipped house. Secondary electric space heating is now about to become part of the typical equipment stock in single family houses and similar phenomenon is emerging in flats. Mechanical ventilation was included as part of a typical equipment stock in detached houses in 2006 and now in 2011 it is emerging as part of the high equipment stock in flats. A dishwasher and a computer which in 2006 were part of the appliance stock of a highly equipped flat became part of the typical equipment stock of a flat in 2011, hence the increases in home electronics and cooking and dishwashing. The increased energy efficiency of home electronics show as a reduction in consumption only in highly equipped households, most notably in flats were the volume effect is negligible. The total electricity consumption is increasing in all of these four reference households. Only one of the eight reference household defined in 2006 and 2011 show a slightly decreasing trend namely a family of three in flat. See figure 7 for details.

This analysis suggests that the heating related electricity end uses will continue to increase in importance. Mechanical ventilation and heat pumps in principle enhance energy efficiency though they increase electricity consumption when the heating energy used is not electricity.

Lesson from data analysis

The reliability of survey data is often questioned and it is true that the formulation of the questionnaire affects the answers. People cannot answer to questions they do not understand nor if they do not know the answer. Badly designed questions are not a fault in the method, but a fault in the execution. People not knowing the answer on the other hand indicate issues that might need addressing in communication. Further, analysis of data and model testing may reveal unexpected patterns and these in turn indicate issues for further investigation. The following are examples of the issues that emerged in the analysis of 2011 data:

- 32 % of households living in block of flats did not know the heating energy of the apartment block, in row houses this percentage was 8 % and in single family houses 0 %. In population terms, 15% of households did not know the energy source of the two largest residential energy end use components. Targeted communication is obviously needed.
- People in flats also lack knowledge on the ventilation system of the apartment block and the share of apartment specific mechanical ventilation was not as high as expected in the flats built after 2000. The likely reason for this is that the occupant is unaware of the systems existence. The other alternative, severe breach of existing building regulations, is much less likely. This also has communication implications.
- The variance of total electricity use per square feet of living area in houses heated with electricity was lower than that of houses heated with ground source heat pumps. (The data was controlled for the year of construction.) This indicates that similar performance problems to those found in Energy Saving Trust's heat pump field trial [11] may be present in Finland.
- The testing of the model revealed that domestic water consumption is lower in houses risking running out of hot water. This is the case when hot water is produce night time taking advantage of the time of use tariff, a practise very common in Finland. Similar results to this can be found in measurement studies from the 1980's in Finland.
- The construction year did not affect the energy consumption as much as expected and the observed trends were in line with those of Norway and Sweden. This indicates that the prebound effect introduced by Sunikka-Blank and Galvin could also be present in Finland [13].

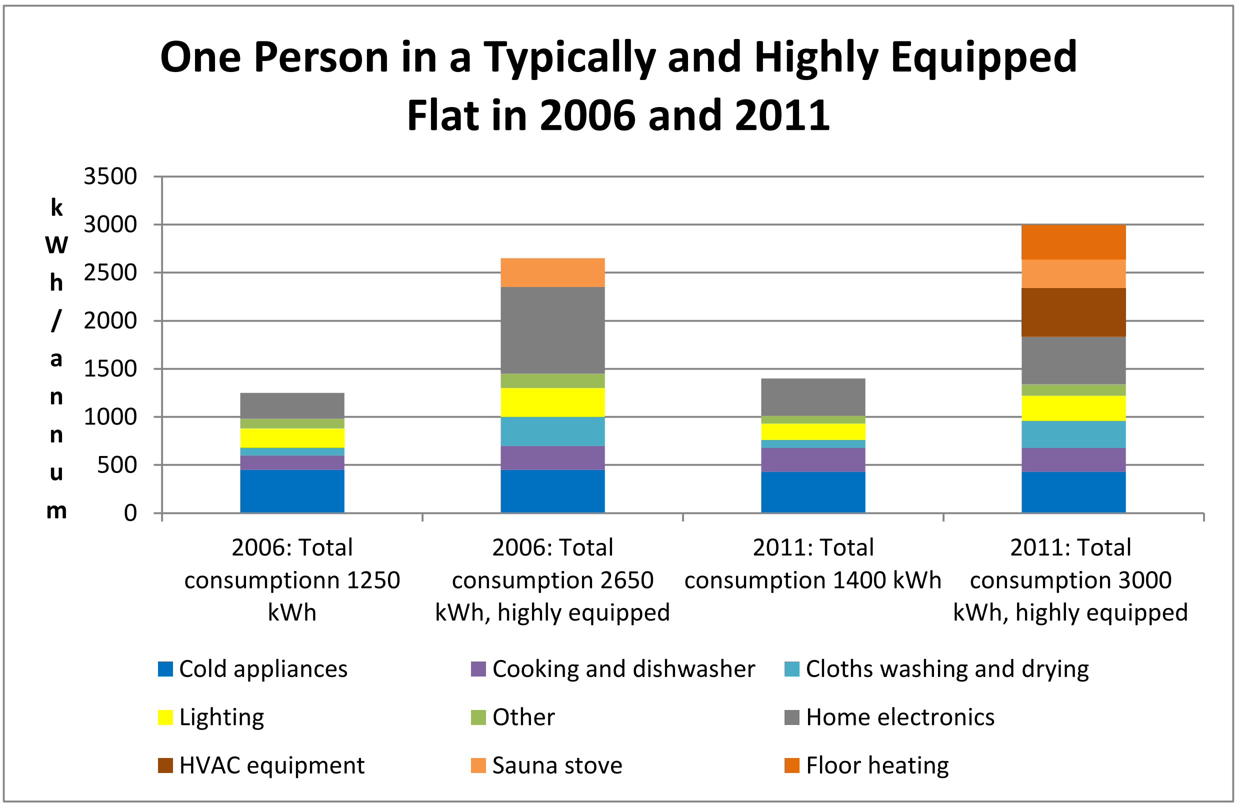

Figure 5. Reference household, one person in a flat.

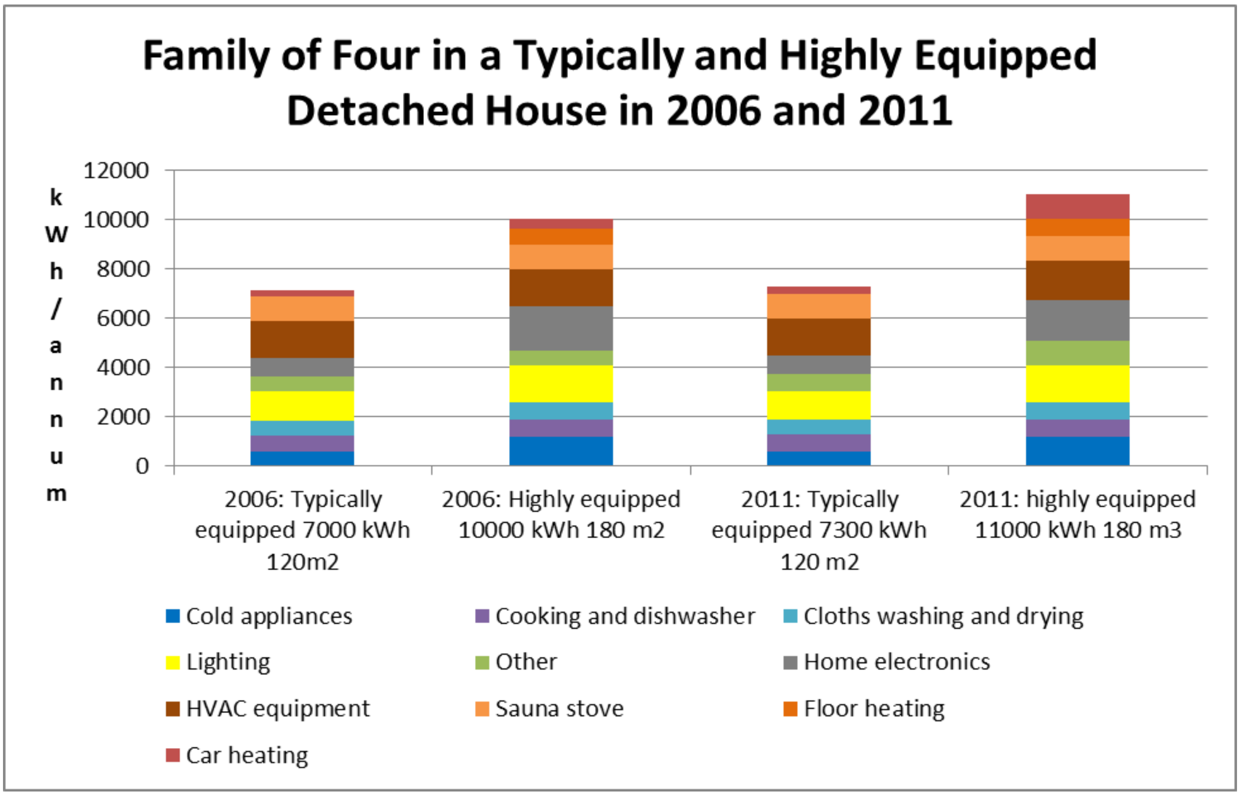

Figure 6. Reference household, a family of four in a detached house

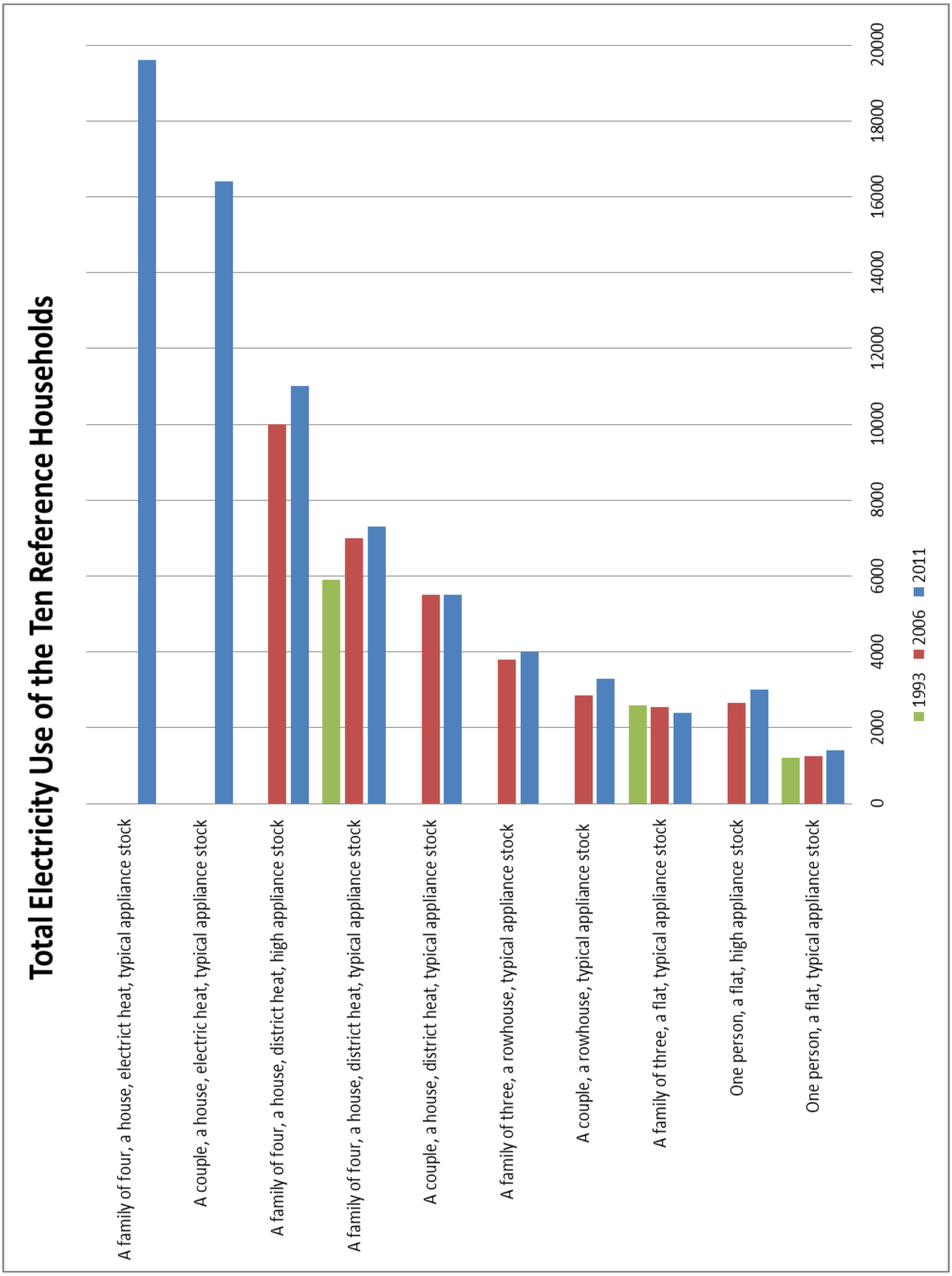

Figure 7. Summary of the total annual electricity use in reference households in 1993, 2006 and 2011.

Conclusions

Electricity consumption in households has increased by more than two terawatt hours (TWh) from 2006 to 2011 and is now close to 20 TWh. The increase is due entirely to the increase in electricity consumption associated with the heating of homes. A number of factors contribute to this development. The most important are increased number of heat pumps, increased secondary electric heat and increased mechanical ventilation and heat recovery.

The electricity consumption of household appliances is on the same level as before, because the reduction in consumption in lighting and TV appliances offset the increased electricity consumption of computers, dishwashers and car heating.

The reduction in consumption is attributable to the regulations issued under the EU Directive on Ecodesign. Electricity consumption for lighting is approximately halved. Lighting accounts for only 8 percent of electricity consumption in the residential sector, while the share in 2006 was 14 percent.

The electricity consumption of TVs fell 32 percent over five years and represent now just 3 percent of electricity consumption in households. Their number hardly increased and much of the equipment was replaced with new ones during 2007-2010. In most of the new TV sets it is the consumption in standby and off mode under 1 W, which explains this share reduction in electricity consumed.

The electricity consumption of IT devices increased rapidly, doubling in the past five years as the equipment became more common. The increased efficiency brought by the switch of desk tops to lap tops was not large enough to compensate for the increased volume. he number of computers has increased dramatically and fewer households cope without a computer and broadband connection. The proportion of such households was only 15 percent in 2011, while their share even in 2006 was as high as 40 percent.

Number of smaller lessons can be drawn from the data analysis. These include a need to improve customer information on heating and ventilation especially in the segment flats, need to investigate further the actual performance of heat pumps in the field and effect of technology and price incentives on water usage patterns.

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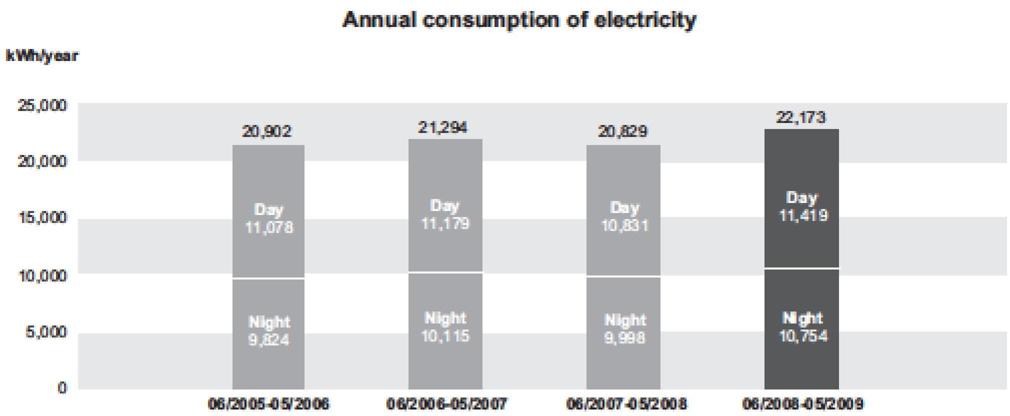
APPENDIX 1: A Model of the Year Report of the Household customers, time of use tariff

adato

YEAR REPORT
10 June 2009

Customer	Eric Electrician
Address of the metering point	Substation Road 2 86000 Town
Metering point ID	12345689

Basic model (two-rate product)



Your household's annual electricity consumption for the period 06/2005-05/2009 is presented in the graph.

You can compare your electricity consumption with other users by looking up a similar household in the comparison table on the reverse side. The tables comprise the data of several thousands of electricity users. Further information on the comparison is available on the website www.motiva.fi/kayttoraportti/.

Tips

You may get an unpleasant surprise if your home electronics are kept switched on at all times. For example, a PC that is always on may consume as much as 1,000 kWh of electricity a year. This equals the annual consumption of an electric sauna stove in a detached house.

Further information

The following websites provide further information about efficient use of energy:

www.vinkkilista.fi
www.energianeuvoja.fi

Please turn over

Comparison tables – LOOK UP THE GROUP CORRESPONDING TO YOUR HOUSEHOLD

Other than electrically heated households – comparison figures

kWh/year

Number of occupants / Type of dwelling		1	2	3	4	5	6
Detached or semi-detached house	economical consumption	3,500	4,500	5,600	6,600	7,600	8,600
	average consumption	5,000	6,000	7,000	8,000	9,000	10,000
Terraced house	economical consumption	1,730	2,700	3,200	3,700	4,000	4,200
	average consumption	2,400	3,700	4,200	4,700	5,000	5,200
Block of flats	economical consumption	1,090	2,000	2,500	3,000	3,500	3,700
	average consumption	1,500	2,500	3,000	3,500	4,000	4,200

Electrically heated households – comparison figures

kWh/year

Floor area m² / Type of dwelling	**under 40**	**41-60**	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-180**	**181-200**	**201-250**	**over 250**
Detached or semi-detached house											
economical consumption	3,113	6,249	10,431	14,082	16,168	17,732	19,297	21,383	23,484	26,631	29,773
average consumption	5,707	8,853	13,039	16,689	19,297	21,383	23,469	25,556	28,181	31,331	34,474
Terraced house or block of flats											
economical consumption	2,477	5,191	8,957	12,185	13,852	14,997	16,143	17,809	19,476	21,871	24,475
average consumption	5,056	7,787	11,561	14,789	16,976	18,643	20,309	21,975	24,163	26,558	29,162

Holiday homes

kWh/year

	ELECTRICITY CONNECTION, NO ELECTRIC HEATING				ELECTRIC HEATING			
Floor area of holiday home m² / Use of holiday home	**under 60**	**61-100**	**101-140**	**over 40**	**under 60**	**61-100**	**101-140**	**over 140**
Summer season	250	500	1,000	1,500	500	1,000	2,000	3,000
Six months	500	1,000	2,000	2,500	2,000	4,000	8,000	9,000
Constant use	1,000	2,000	4,000	4,500	4,000	8,000	16,000	18,000

Average annual electricity consumption describes normal electricity use in each group. A quarter of the households in each group consume less electricity than the figure for economical consumption. Only average annual consumption is given for holiday homes.

The amount of electricity used for heating depends strongly on the heating need, which varies in different years and locations. The comparison figures for electrically heated households are adjusted to the temperature of a normal year in accordance with the location of your metering point. The temperature of the normal year is calculated as average of actual temperatures over 30 years. Further information about the temperature adjustment is available on the website www.motiva.fi/kayttoraportti/.

Assessment of electricity consumption explanatory factors for large electrical appliances

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Enerdata

Didier Bosseboeuf

ADEME

Abstract

This paper aims at identifying and quantifying the main factors influencing electric consumption for large electrical appliances. Results are illustrated in the case of France and Germany.

The role of various factors have been considered: appliance ownership, appliances' size, efficiency level according to energy label class, equipment features, equipment price according to respective energy efficiency, consumer attitude, and electricity tariffs. A technico-economic decomposition analysis of energy demand changes has been developed to quantify each factor's impact for five of the main observed factors. The analysis has been carried-out by type of appliance. The results show that only two factors significantly impact consumption: the equipment ownership rate and the energy label penetration; however, they tend to offset each other. Qualitative factors (e.g. behaviours, retailers' strategies, policy factors) have been also considered and some of which were assessed. In conclusion we will show how these factors explain the difference in the specific consumption of appliance in France and Germany.

Context and objectives

Residential electricity consumption for domestic appliances and lighting is on average steadily increasing: the unit consumption per dwelling for lighting and electrical appliances has been increasing by 1.3% per year at EU level during the period 1990-2008 (Figure 1), and up to 4% per year for Greece, Cyprus or Ireland[1]. This paper aims at identifying and quantifying the main factors influencing electric consumption for large electrical appliances. To illustrate the different trends, we will study in particular the cases of France and Germany, where detailed data by appliance type were made available[2].

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[1] The trends are on purpose shown over the period before the start of the economic crisis.

[2] http://www.odyssee-indicators.org/publications/PDF/Summary-benchmark-electricity-EN.pdf

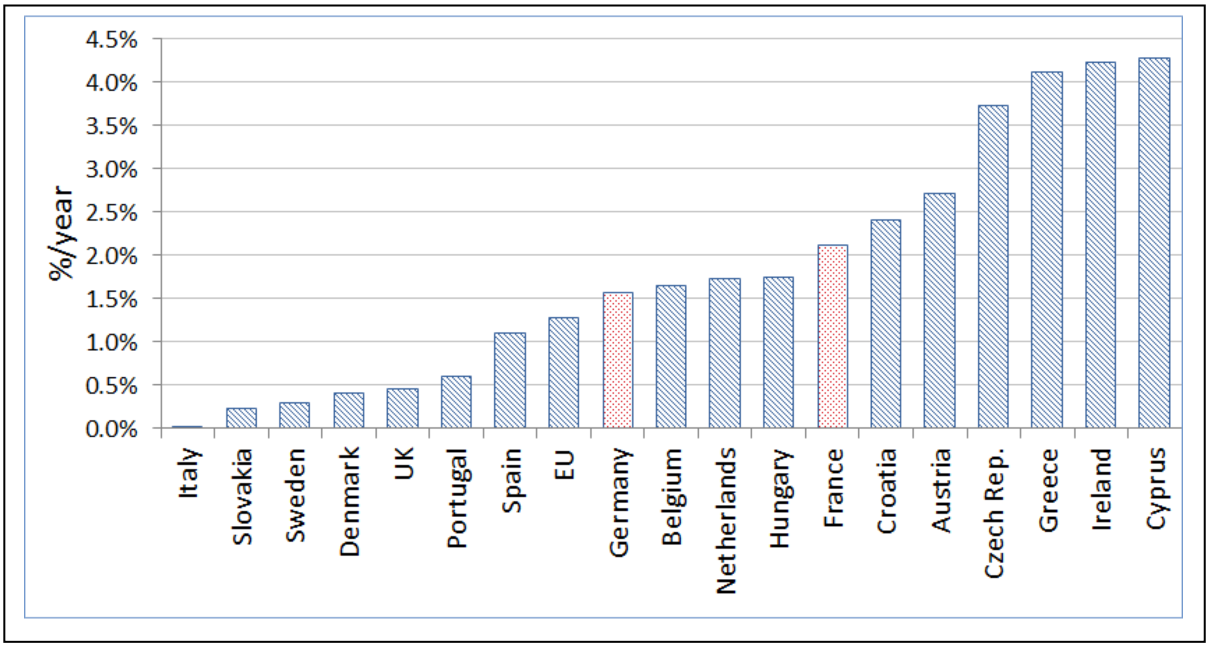

Figure 1. Annual trends in household electricity consumption for appliances and lighting between 1990- 2008

Source: Odyssee

Driving factors of the energy consumption

The analysis focuses on large domestic appliances, which present the largest available set of data and consume more than 40% of captive uses, on lighting (which accounts for 15% of specific electricity), and on the main consumer electronics (TV, computers). As shown in Figure 2, we will try to understand the factors behind the changes in the household electricity consumption of large appliances, so as to asses why it been increasing in France since 2008 and not in Germany. Several explanatory factors will be considered such as:

- **Equipment rate** in large appliances, home entertainment electronics (TVs, PCs) and lighting;
- **Appliances' size**, especially for cold appliances and TVs;
- **Equipment features and functionalities** impacting consumption (upright versus chest freezers; frost-free and built-in cold appliances);
- **Efficiency level** according to energy label (A, A+, etc.); for the diffusion of the different class we will take into account the equipment price for energy efficient classes and the potential role of electricity price.
- Finally, the **consumer behavior** (frequency of use and preferred temperature for washing appliances; duration of use of TVs and lighting equipment);

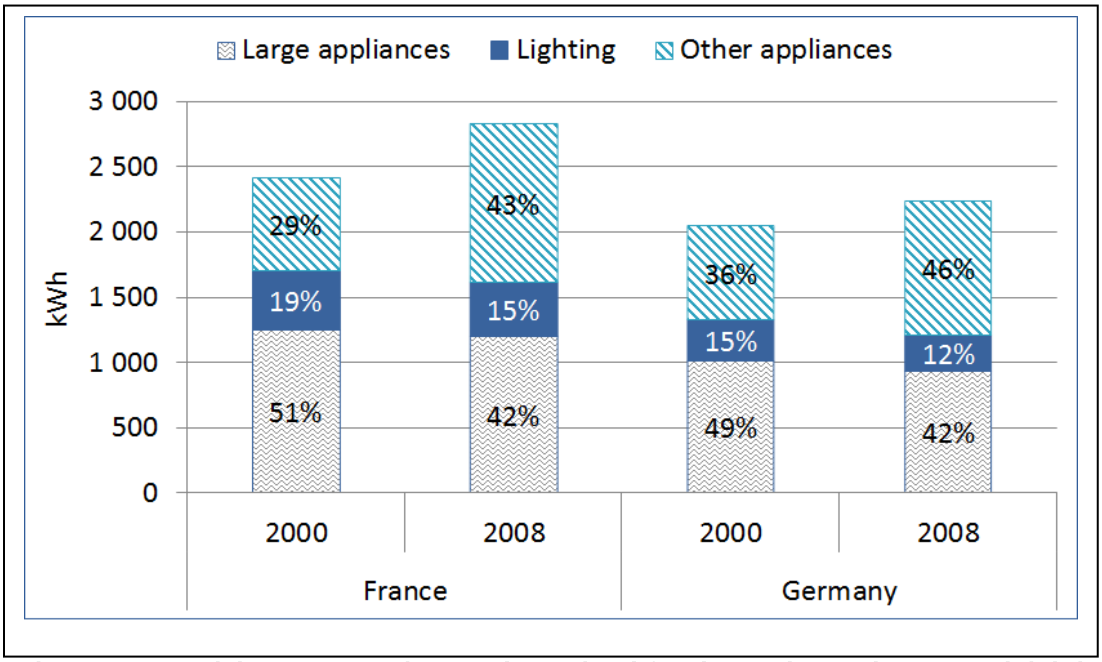

Figure 2. Electricity consumption per household for domestic appliances and lighting by end-use in France and Germany

Source: Odyssee

Large domestic appliances

Equipment rate and size

Except washing machine where equipment rates were roughly steady during 1990-2008, for all other large appliances their diffusion increased, especially for freezers, dish washers and dryers. For instance we observe an increase of 34 points in Germany for dish washers and of 20 points in France for freezers and dryers (Figure 3). Although both countries' equipment rates are close, Germany's rates are higher. But France is gradually reaching similar rates, in particular for freezers, refrigerators, and washing machines.

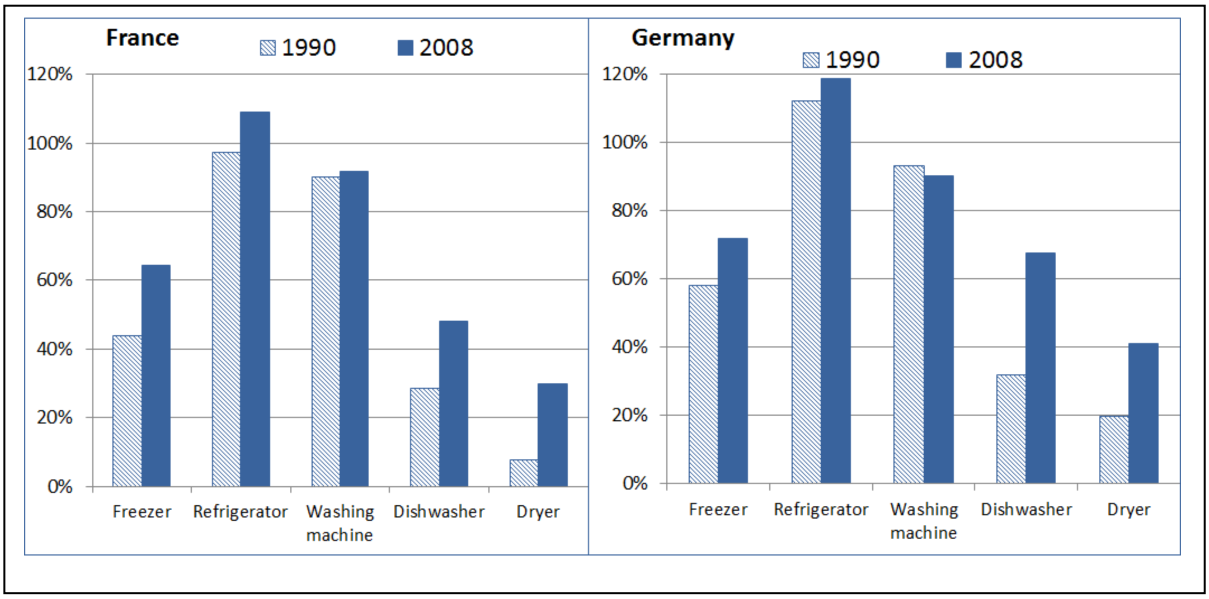

Figure 3. Equipment rate in France and Germany

Source: Odyssee, INSEE, SOFRES

For large domestic appliances, the size of new appliances has been increasing: since 2004, increase of 2% for fridges sold in France (and almost +7% in Germany), average size increase of 2% for freezers in both countries and significant increase for washing machine capacity (+20% in both countries, Figure 4).

Refrigerators and freezers sold in France are larger than the ones sold in Germany (+30% and +23% respectively): it may be partly explained by the average size of household, i.e. the average number of inhabitant per household, that is 13% higher in France, and by the fact that dwellings are on average smaller in Germany (by about 9%), due a larger share of apartments compared houses. The size difference for washing machines and dishwashers is hardly significant.

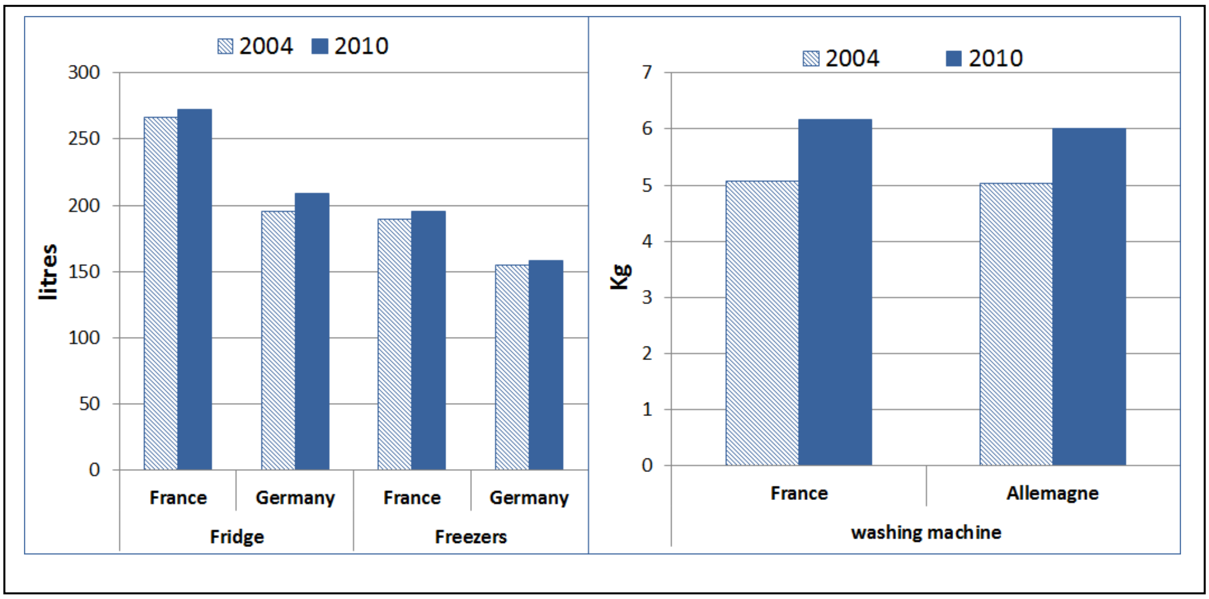

Figure 4. Average size of new appliances in France and Germany

Source: GfK, Enerdata calculation

Equipment types and functionalities

Sales of less electricity intensive cold appliances' (table-top, 1 and 2-doors[3]) are decreasing since 2004 in both countries: from 77% to 67% of sales in France and from 75% to 56% in Germany between 2004 and 2008. And the sales of these "less intensive equipment" are higher in Germany than in France (Figure 5). French consumers buy twice the number of frost-free refrigerators (32% of French sales in 2008, versus 11% in Germany). This system is more energy intensive. On the contrary, the German market share of built-in refrigerators, which are less energy-efficient, was 41% in 2008 vs. only 15% in France.

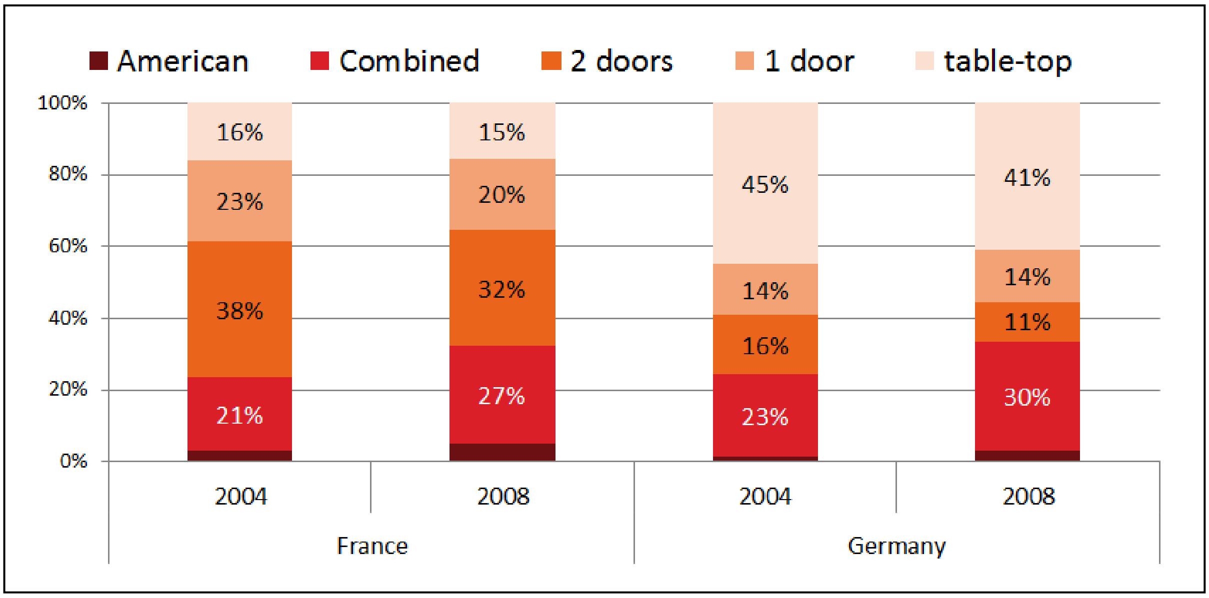

Figure 5. Sales of fridge according to main features in 2004 and 2008

Source: GfK

The market share of upright-freezers', which are more energy intensive than the chest type are slightly increasing over time (Figure 6). It is 30 % larger in Germany than in France. Frost-free freezers' market share is also higher in Germany (23% vs. 10%). Freezers sold in Germany are thus more energy intensive than the appliances sold in France.

[3] "Table-Top" models are 1-door refrigerators, with a 90 cm maximum height.

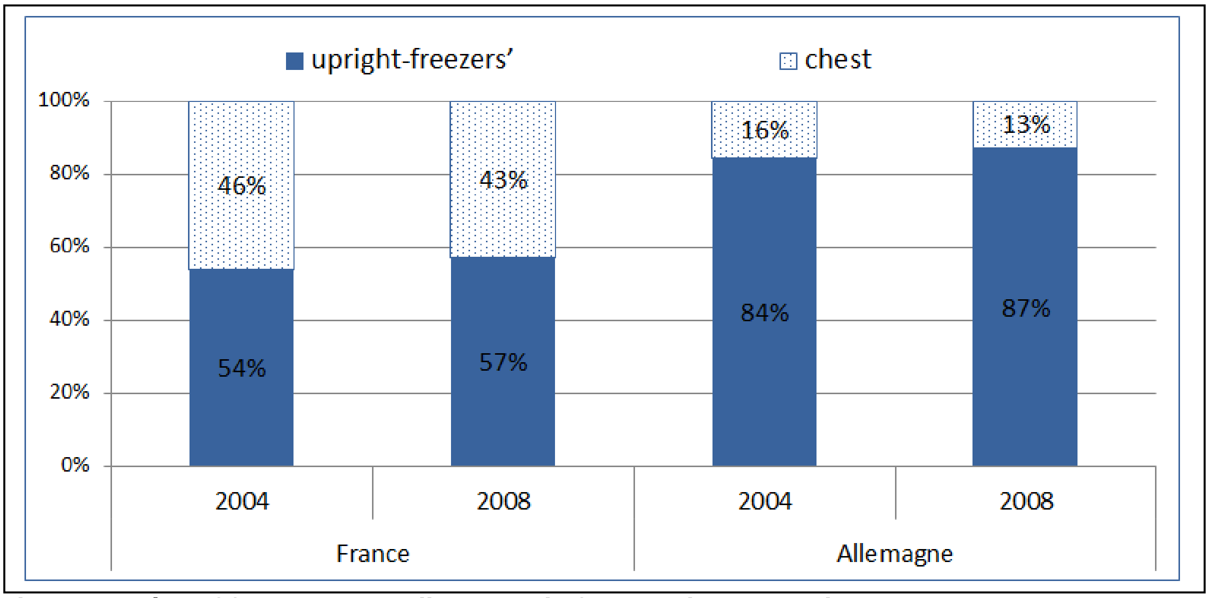

Figure 6. Sales of freezers according to main features in 2004 and 2008

Source: GfK

Front-loading washing machines' sales are higher in Germany (90% vs. 59% in France), but their share has been quickly increasing in France (from 25% in 2000 to 59% in 2008). Top-loading washers are usually less efficient than the front-loading type[4].

Since 2004, the sales of less efficient type of equipment are increasing, such as combined or American fridges or upright freezers. While refrigerators and washing machines bought in France are overall more energy intensive than in Germany, German consumers tend to buy freezers with more energy intensive functionalities than the products favoured by French consumers.

Equipment efficiency

Thanks to the Energy Labelling Directive the share of energy efficient appliances has remarkably increased since 2002, but at a different pace among countries (Figure 7). The penetration of very energy efficient appliances[5] has been much higher in Germany than in France: in 2010[6], A+ rated washing machines' market share is 10 points higher in Germany; the share of A+ and A ++ labels is respectively 34 and 47 points higher for refrigerators and freezers.

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[4] Top-loading washing machines lower efficiency level can be explained by their relative small market share, and by the fact that manufacturers choose to invest in the front-loading range optimisation.

[5] For washing machines the most efficient label is officially A but manufacturers are allowed to use "A+".

[6] There has not been massive subsidy programmes in Germany to explain such differences. Prices are on average lower in Germany for the most efficient appliances (e.g. 10% of difference for a given A++ freezer), because demand for these types of product is higher thanks in particular to awareness programmes and the marketing strategy of suppliers and resellers(see below for further explanations). There has not been massive subsidy programmes in Germany.

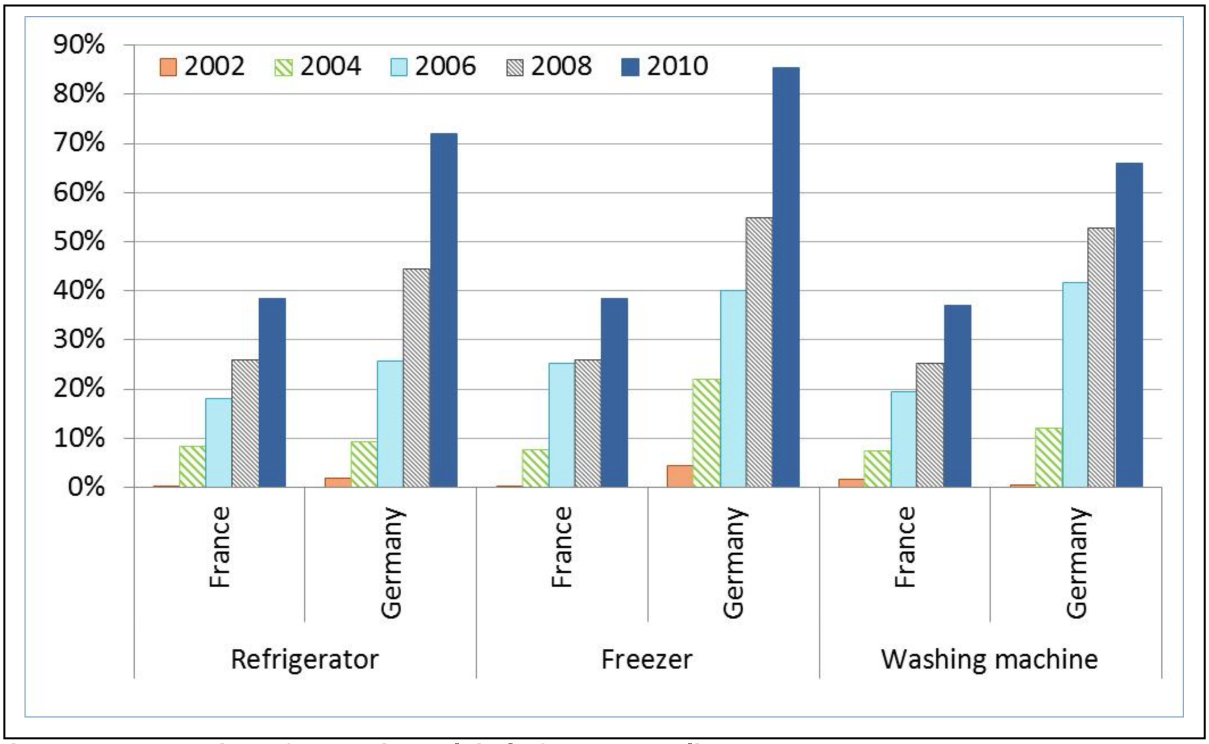

Figure 7. Penetration of A+ and A++ labels for new appliances

Source: GfK

These different trends between France and Germany may be partly linked to the fact that efficient appliances are cheaper in Germany than in France and that the price of electricity is twice higher in Germany.

Most energy-efficient cold appliances are more expensive in France than in Germany. The price difference can reach up to 20% for class A+ or A freezers and 13% for A+ refrigerators. In addition, the price difference between an A and an « A+/A++ » washing machine is higher in France than in Germany (39% vs. 23%).

Sales prices according to the energy label are partly determined according to market shares. High efficient appliances (A++ and A+) market share is notably lower in France compared to Germany. The price difference can be explained by the smaller size of the market, and the lack of trust of manufacturers in the French consumer "green" awareness, which leads them to market less energy-efficient models.

The average electricity price for households in France is currently about half of the German price[7]. Half of the difference can be explained by cost differences and the other half by a different level of taxes. VAT weighs equally in both countries (around 15%). Other taxes are much higher in Germany, accounting for 27% of electricity total price (of which an 8% eco-tax since 2000), versus 10% in France[8].

Behaviours

[7] Source : Enerdata Global Energy & CO2 data.

[8] Source : IAE Statistics, Energy prices & taxes – quarterly statistics.

If Germans use higher temperature[9] water to wash their laundry and dishes than French households, they will use more frequently economic cycles. In addition, German households tend to load more their washing appliances, reducing the number of cycles and the electricity consumption (Remodece, 2007[10]).

French households declare cleaning the refrigerator's rear grid more often (25% monthly vs. 5% in Germany; and 38% once a year in France vs. 15% in Germany (Remodece). French consumers defrost their refrigerators and freezers more often. In Germany, over 20% of respondents declare having set the thermostat on the lowest temperature, vs. only 3% in France (Remodece).

Although it is impossible to quantify each attitude's impact in terms of consumption, they tend to partially compensate each other, and hardly play a part in the observed consumption discrepancy.

Lighting

Lighting electricity consumption is decreasing over time in both countries by 1.4%/year (Figure 1). However, it is notably higher (+49%) in France than in Germany in 2008. This consumption gap does not lie in the number of lighting points, because it is identical in both countries: 25 lights on average per household.

In contrast, the German households have installed twice as many compact fluorescent lamps as in France (6,5 /house in Germany vs. 3 in France). Compact fluorescent lamps' penetration can explain most of the difference in consumption. According to Remodece report, the differences in consumers' attitude for lighting offset each other.

ICT appliances

The average number of TVs per household is similar, with around 1,5 TV/household in 2008 in both countries. TV size and duration of use are also close and increasing over time (Figure 8).

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[9] In Germany 50% of households wash their laundry at 65°C vs 29% in France. In Germany, 44% of households wash their dishes at 65°C vs. 21% in France.

[10] This study involved a panel of 500 households in the two countries. Although it was led in 2006, it helps understand consumers' attitudes differences between the two countries "Residential monitoring to decrease energy use and carbon emissions in Europe"; EIE project, 2007.

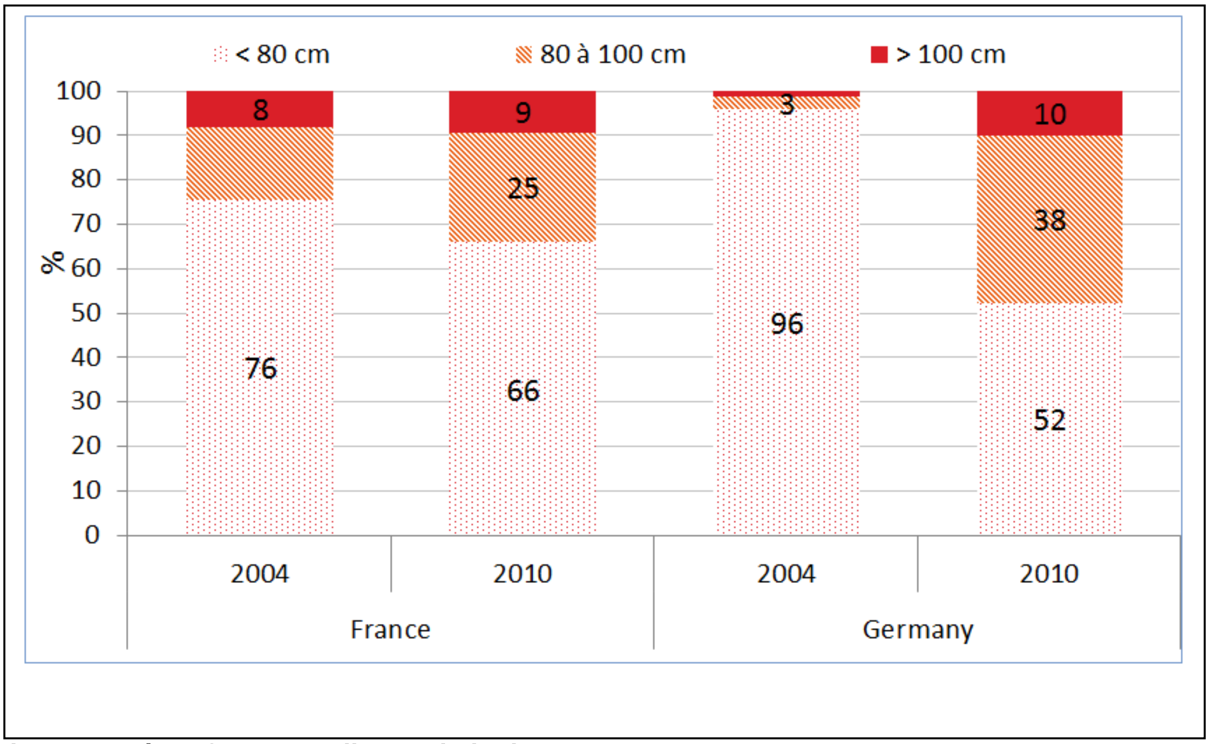

Figure 8. Sales of TV according to their size

Source: GfK

The equipment rate in computers is higher in Germany. Screens sold in Germany are slightly larger than the models sold in France: *21" vs. 20" in 2010.*

Laptops spreading encouraged multi equipment in PC's. The average number of PCs per household has grown from 56% in 2003 to 103% in 2010 in France; and from 82% to 110% in Germany. It has been paired with the Internet development, resulting in a higher penetration rate in Germany than in France (82% et 75% en 2010).

Set-top-box systems have also rapidly grown in the last ten years, again spreading faster in Germany than in France.

With a higher equipment rate in PCs, electricity consumption is also higher in Germany: in 2008, the consumption of these three appliances accounted for 200 kWh in France and 250 kWh in Germany.

Factors responsible for the consumption variation of all electrical appliances in both countries

In order to quantify the effect of the different factors on the consumption variation, a bottom-up model was developed to simulate the change in the specific consumption of the stock of the different appliances based on the characteristics of the appliances sold every year in France and Germany over the period 1990-2010[11]. For that purpose a detailed database was compiled with information per

[11] The model simulates the consumption of new appliances sold per year as well as the average annual consumption of the stock based on the evolution of equipment rate and market shares of energy labels from 1990 to 2010. The final results for

country regarding sales of appliances, rate of equipment, stock of appliances, type of appliance and specific electrical consumption per energy efficiency class.

For each appliance, different types or categories depending on some particular characteristics were considered, such as the layout of a freezer or the average load of clothes for a washing machine (see previous analysis). Thanks to this model, several parameters that affect the electrical consumption of appliances such as types of appliances, energy labelling and penetration of new equipment can be identified and their impact can be estimated.

Figure 9 shows how much the consumption of all major electrical appliances has changed between the years 2000 and 2009 in France and in Germany and what factors are responsible for this change. The factors for which the effect on the electrical consumption have been quantified are the equipment rate, the total stock of permanently occupied dwellings (effect of demography), the shares of new appliances sold per energy class and the specific consumption of new appliances sold per energy class (energy efficiency effect).

It can be observed that total electrical consumption for large appliances (fridge, freezers, washing machine and dish washer) in France has risen by nearly 3 TWh. The growing number of households and increasing equipment rate have strongly contributed to this rise (for the equivalent of 7 TWh); this increase has been partially offset by almost 4 TWh of energy savings caused by energy efficiency improvements, namely energy labelling. In other words, without any energy efficiency measures France's electrical consumption would have risen by 7 TWh. The rise of the total consumption in Germany is considerably smaller compared to France (around 0.2 TWh). The effect of demography is almost half as significant compared to France, whereas the increase of equipment rate is analogous to the French one. In addition, the impact of energy efficiency measures is stronger than in France, resulting in energy savings of 4.5 TWh.

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every appliance were compared with other relevant studies, such as the "Benchmarking of Domestic Cold Appliances" by IEA 4E and the "Reestimation en 2005 de la consommation d'électricité par usage fin" by CEREN.

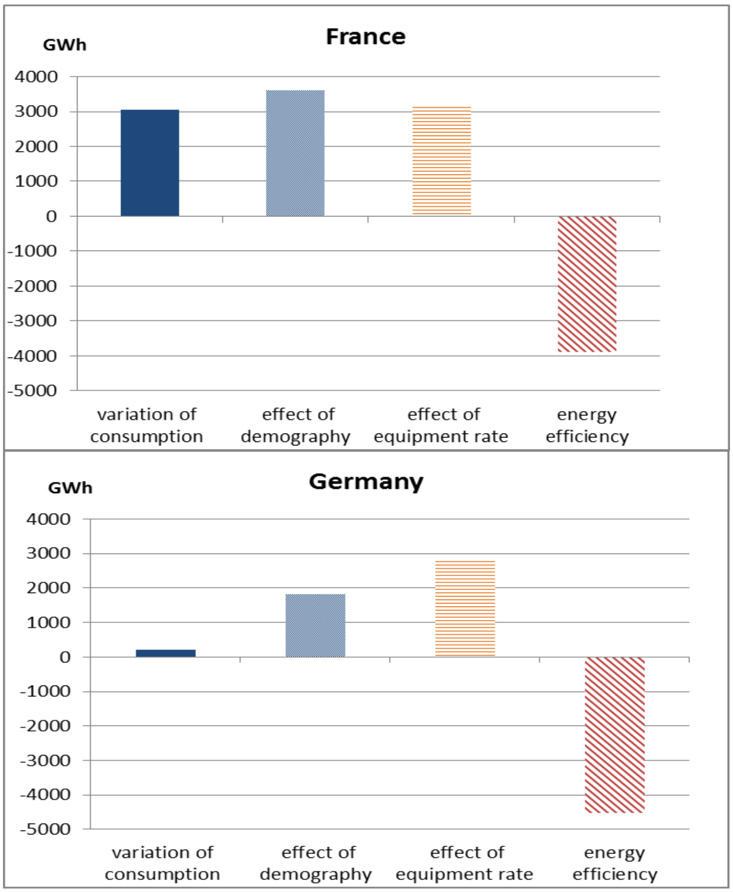

Figure 9. Factors responsible for the total variation in the consumption of all electrical appliances in France and Germany between 2000 and 2009

Source: Enerdata

Comparison between France and Germany

As seen above in Figure 2, France is not performing as well as Germany regarding captive uses of electricity[12]. A benchmarking of household specific electricity consumption in ODYSSEE (2012) shows that households' specific electricity consumption was 26% higher than in Germany in 2008[13] (Figure 10). Italy and Spain are also in a better position. However their good ranking can mainly be explained by the lower income and consequent lower equipment rate, compared to France[14]. To explain the gap between France and Germany and in particular as to the role of the different factors presented above, adjusted indicators of specific electricity consumption have been designed to quantify each factor's impact in the observed discrepancies between the two countries.

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[12] Captives uses, also referred to as "specific electricity uses" or "specific electricity consumption" in short, include all non-thermal uses, i.e. small and large domestic appliances, consumer electronics and lighting.

[13] 2008 is the preferred reference due to 2009's particularity with the economic crisis.

[14] In addition, most Italian households benefit of a 3kW subscription contract, because of inclining electricity tariffs, which limits their consumption level.

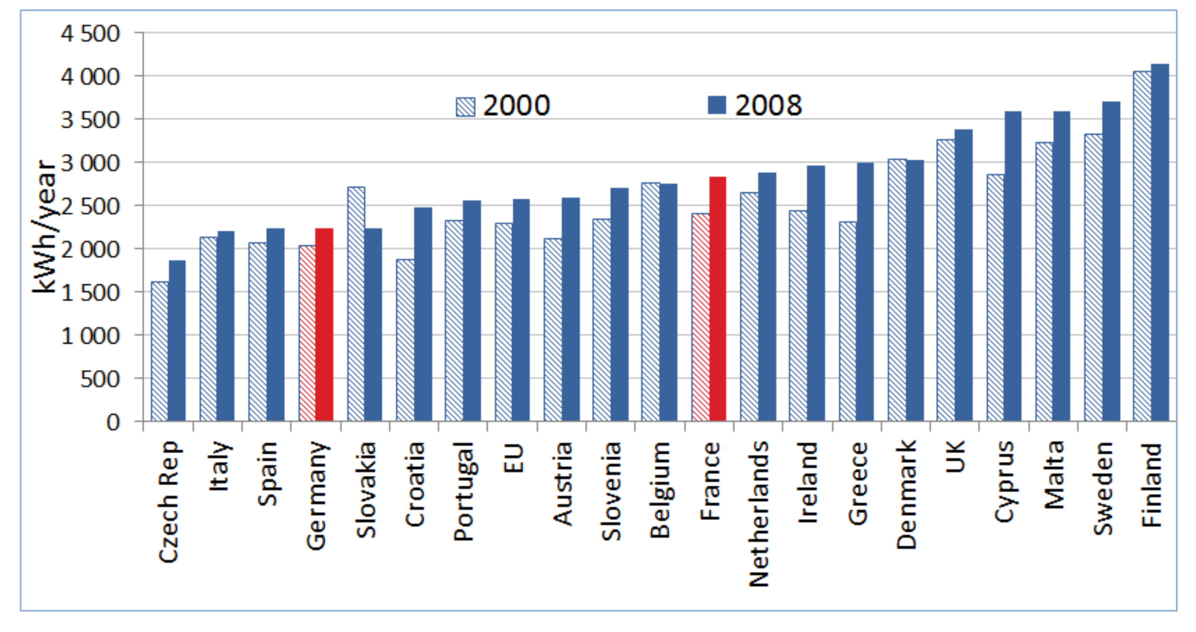

Figure 10. Household electricity consumption for appliances and lighting

Source: Odyssee

Adjustments have been made on the following factors of differences between France and Germany: equipment rate and size (for large domestic appliances[15]), energy labels penetration (for large domestic appliances and lighting), and appliances' features and frequency of use (for washing machines). They have been calculated for each appliance (fridge, freezer, TV, etc.) and then sum up by type/group of appliance: large domestic, lighting, consumer electronics and small electric appliances. This allowed calculating for each of these factors a fictive Germany's specific electricity consumption adjusted to French conditions: for example, with the equipment rate adjustment, we apply the rate observed in France to Germany for each type of appliance to calculate the fictive specific consumption of Germany adjusted to French equipment rate, all else being equal.

Adjusting the German unit consumption to the French equipment rate enlarged the initial gap between the two countries from 26% to 33,5% (Table 2).

Table 1. Adjusted Germany's electricity consumption to France's equipment rate (2008)

kWh/household/year	Large domestic	Lighting	Consumer electronics	Small electric appl.	Other	Total
Germany	929	278	569	394	67	2,237
Germany, adjusted to equipment rate in France	**820**	278	**507**	**445**	67	**2,117**
France	1,195	414	507	425	284	2,825

Source: Odyssee, adjustment calculation Enerdata

[15] Large domestic adjustments were calculated thanks to a model simulating stock evolution from annual sales (to take into account the impact of new appliances sold since 1990 and according to different criteria: label, type and size of appliance).

The adjustment for the higher penetration of efficient appliances in Germany reduced the spread between the two countries, from 26% to 15% (Table 2): in conclusion, 40% of the gap could be explained by the difference in penetration of highly efficient appliances.

Table 2. Adjusted Germany's consumption to France's energy label penetration rate (2008)

kWh/household/year	Large domestic	Lighting	Consumer electronics	Small electric appl.	Other	Total
Germany	929	278	569	394	67	2,237
Germany, adjusted to energy label penetration in France	**1,002**	**372**	569	394	67	2,404
France	1,195	414	507	425	284	2,825

Source: Odyssee, adjustment calculation Enerdata

The adjustment of German specific consumption to the average size of appliances sold in France only reduces slightly the spread from 26% to 25%. This means that the size of large domestic and lighting equipment[16] plays a minor role. Technical features and functionalities have also a marginal impact as the adjustment only shows a reduction of the difference by 2 points. And finally, when adjusted to frequency of use in France, the German specific consumption only increases marginally (20 kWh).

The respective weight of the above five adjustments differ, as only two adjustments significantly impact the specific electricity consumption: the equipment rate and energy labels penetration. Unfortunately, these two factors partly offset each other, which cannot explain the total performance gap between France and Germany. The calculation shows that only 21% of the observed difference can be explained by these factors (Figure 11).

[16] Indeed, the equipment rate for lighting corresponds to the number of lighting points, which is the same in France and Germany: on average 25 lighting points per dwelling.

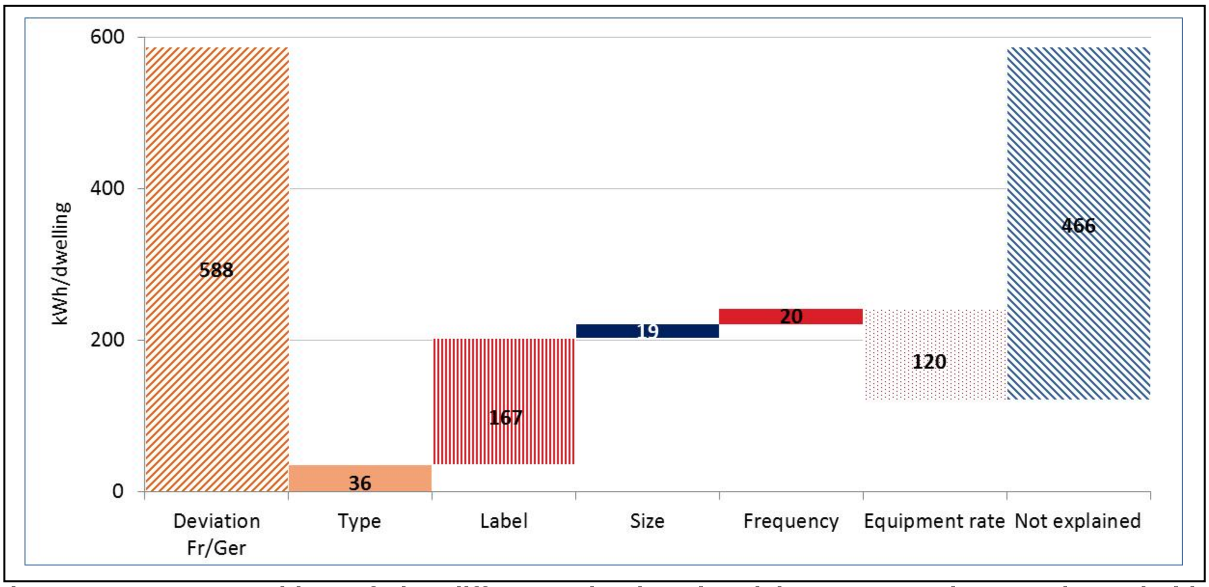

Figure 11. Decomposition of the difference in the electricity consumption per household between France and Germany for captive uses

Source: Enerdata

Conclusion

Thanks to several existing databases (GfK, Odyssee, etc.), the main driving factors behind the change in the residential electricity consumption for domestic appliances have been analysed for France and Germany. To complete this descriptive analysis, a model was developed to provide a complete evaluation of the impact of these factors on specific energy consumption of new products sold as well as the stock of electrical appliances over the period 1990-2010. The results show that indeed equipment rate, total stock of households, size of appliances, and market shares of efficient equipment and behaviour influence the electrical consumption of appliances at a country level. Differences in these parameters from country to country could explain why a country has a better performance that another.

Two main factors partly explain the higher specific consumption in France:

- Large domestic appliances are larger in France than in Germany: over 20% larger refrigerators and freezers, which are both the most common and the most energy consuming appliances in households.
- A larger penetration of very efficient large appliances in Germany (washing machines, cold appliances, and lighting), which can mostly be explained by the lower price of these products in Germany.

In order to quantify the respective impact of these factors, we have calculated a fictive specific consumption per household for Germany adjusted to France's specificities. The results show that only two of the five adjustments significantly impact the consumption: the equipment rate factor and the energy label penetration; however, they tend to compensate each other. As a result, the five adjustments only account for 21% of the performance gap observed between France and Germany, i.e. 125 kWh for an initial difference of approximately 600 kWh.

How could the residual gap be explained? One can think of qualitative factors such as prices, policies and all other qualitative factors reviewed above. Electricity is 50% cheaper in France; it certainly plays a role, but an econometric analysis carried out in the framework of the study failed to quantify the impact. It could be linked to statistical problems[17]. The analysis of policy instruments in France and in Germany shows that Germany has implemented public awareness programmes for longer that France, and with more continuity and that German households benefit from numerous DSM programmes implemented locally by Länders, cities, and more than a thousand electricity providers.

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National French Institute of Statistics, INSEE, http://www.insee.fr/fr/themes/document.asp?ref_id=T10F062

TNS SOFRES, http://www.tns-sofres.com/

GfK, http://www.gfk.fr/

REMODECE, http://remodece.isr.uc.pt/   First reference, 1992, Code of practice for formatting papers.

[17] In particular to the way thermal uses have been assessed to get by difference the captive electricity consumption, especially in the case of France where electric thermal uses are well developed.

GOVERNMENT SUBSIDIES TO REPLACE ENERGY INEFFICIENT APPLIANCES; THE OUTCOME AND IMPACTS ON THE CONSUMERS AND THE LOCAL MARKET

Eddie Bet Hazavdi
Rachel Zaken

Abstract

In 2010 the state of Israel announced a new energy efficiency plan aimed to reduce 20% of the total electricity consumption in 2020 at all the sectors in Israel. During 2011 the Ministry of Energy and Water Resources adopted the "national energy efficiency plan to reduce electricity consumption in 20% by 2020" with a budget of 85 million US$ just for the domestic sector.

Among the activities that were done in the residential sector we introduced a set of new appliances regulation and launched a national project of replacing old and inefficient appliances with new ones. The state subsidizes the replacement of new highly efficient refrigerators, air-conditioners, solar installation and lighting.

The paper will include the outcome of two projects (replacing refrigerators); the regulations and the impacts on the local appliances market (this case, refrigerators).

The paper will focus on the Israeli consumer behavior toward efficient appliance and the changes in the market.

In addition, barriers and obstacles in promoting such projects are identified, and the influence of those projects on energy saving and the indirect benefits is also introduced.

The paper is based on the national energy efficiency program, an appliances market analysis and a research that was conducted to evaluate the influence of the projects on direct energy savings and indirect energy savings.

Introduction

The Energy Conservation and Efficiency Division at the Ministry of Energy and Water Resources works to improve Israel’s energy balance by more efficient energy use and optimal exploitation of energy, and promote the use of alternative energy resources.

The Division takes the lead in all facets of energy efficiency: regulation, enforcement, planning, and initiation and execution of the energy efficiency projects at all sectors.

To meet government's decision, energy savings of at least 20% by 2020, the Ministry of Energy and Water Resources published in 2010, The National Energy Efficiency Program.

According to government resolution, the Division of Energy Conservation and Efficiency will promote energy efficiency activities in the domestic sector, by replacing old inefficient appliances with more energy efficient appliances.

Among other activities the Division proposed a plan to replace via incentive old inefficient appliance with new and highly efficient once. The program was first introduced to an economically weak population and then, added with two projects to the entire population.

In order to determine which refrigerator will be subsidized, bids were given by the producers and importers for three size groups, suggesting best energy efficiency performance. Offers were scored according to energy consumption and performance, lowest price and other characteristics.

Since December 2011 till June 2011, taking advantage of the projects, up to 110,000 households replaced their inefficient refrigerators.

Work purpose

The purpose of this paper is to show the impact of old refrigerators' replacement on the refrigerators' market in Israel, and the change in consumer behavior toward efficient appliances.

Methods

The assessment of attainable energy efficiency was performed for each and every project. In every project a database was built, through a governmental system. Access to the system was for suppliers and appliances stores, each and its own level of access, one refrigerator allowed for each consumer.

The data were examined and then, analyzed, in order to evaluate the savings out of carrying the projects and lessons learned for following projects.

Summary

Electricity production capacity of the State of Israel is not growing at a rate of consumption growth and the state of Israel suffers from chronic limited power supply. The domestic consumption of electricity in the last decade is ranging from 30 to 32 percent of the total annual consumption. In 2002, the domestic consumption was 32 percent and reached 12,747 million kWh and in 2011 reached 15,909 kWh (30 percent of total consumption).

Energy performance and label regulations for refrigerators and freezers came into effect on January 2005. Till then, 500-liter refrigerators' average consumption was about 4.5 kWh a day for non-frost tropical. With the regulation we achieved 2.2 kWh saving for a day per refrigerator.

As mentioned, the first project addressed the economically disadvantage families. According to the Central Bureau of Statistics, the monthly consumption expenditure for electricity is about 25 percent of dwelling and household maintenance expenditures. The relative expenditure for electricity, among the economically weak population, is higher than the relative expenditure for electricity among the economically strong population

Refrigerators offered under the project were divided into three orders of volumes, small, medium and large, 350 to 450 liter, 451 to 550 liter and 551 to 680 liter, respectively. The projects were led with campaign on TV, Radio and other media.

To date, three projects were held and the forth is ongoing. In these projects 110,000 households (5% of the total households), replaced old refrigerators with new, efficient ones. Consumers have shown great willingness to participate in operations, since in the beginning of the projects most of the refrigerators were purchased.

The projects boosted the refrigerators market, changed the energy rating distribution of the refrigerators that are being used by the population, reduced the price level of the refrigerators and change the consciousness of the consumer toward energy efficiency and energy rating at the appliances market.

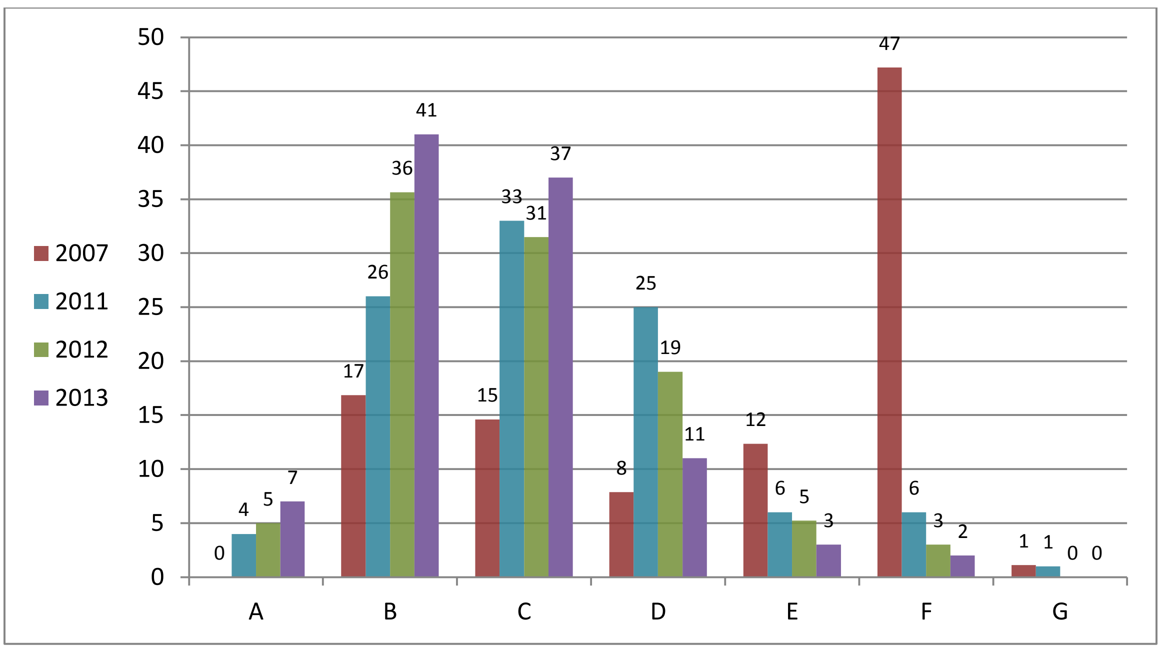
Energy Efficiency Rating

Since 2005 the Energy Conservation Division certifies every year the refrigerators models. A certification and label then issued to indicate the rate for each model. The impact of the project is well seen as the distribution of refrigerators by their rating is moved toward the “B” rating. At 2012, out of 645 models, 73% of the approved refrigerators were rated “A” “B” and “C”. In 2007, out of 89 models, only 36 percent were rated “A” “B” and “C”.

Table 1: Percentage of certified refrigerators, by energy efficiency rating, years 2007 and 2011-2013

Energy efficiency rating	Average annual consumption (For adjusted 500 liter)	Average annual consumption (For 500 liter)	2007	2011	2012	2013
A	082	402	0	4	5	7
B	072	600	17	26	36	41
C	767	705	15	33	31	37
D	407	784	8	25	19	11
E	606	879	12	6	5	3
F	487	870	47	6	3	2
G	607		1	1	0	0

Figure 1: Certified refrigerators, by energy efficiency rating and year



The data in figure 1 reflects the change in the consciousness of consumers, regarding to energy efficiency. The consumers go toward the energy efficient appliances (refrigerators rated A and B). Following the consumers’ requests, the suppliers’ requests, seeking to please the consumers, are to approve more and more A and B rated refrigerators.

The exception value in 2007 - Licensing 47% F-rated refrigerators - is due to toughening the energy rating that year. Changing the standards automatically decreased the rate for many refrigerators models to F.

The effect of the projects held on 2012 is notable. In one year, the weight of requests for B rated refrigerator have grown much higher (from 26% in 2011 to 41% in 2013).

Table 2: Number of certifications by energy efficiency rating (2007-2013):

Energy efficiency rating	Number of certifications
A	64
B	441
C	454
D	287
E	73
F	54
G	4
Total refrigerators approved:	**1,377**

Refrigerators' Energy Consumption

Compared with refrigerators approved before the changes in the regulations, the electricity consumption per adjusted liter fell by 65%. Following the tender requirements, the refrigerators consumption per adjusted liter decreased more by 20%. Refrigerators authorized and purchased under the projects have adjusted consumption average of 0.0020 kWh (small - 0.0022 kWh/liter, medium - 0.0020 kWh/liter and large - 0.0018 kWh/liter).

In 2007 most of the requests were to approve large refrigerators. The average energy consumption per adjusted liter for small refrigerators was the highest and reached 0.0049 kWh. The reduction in energy consumption for the refrigerators in 2012 is 14% for small size refrigerators, 28% for middle size and 25% for large refrigerators.

The Projects

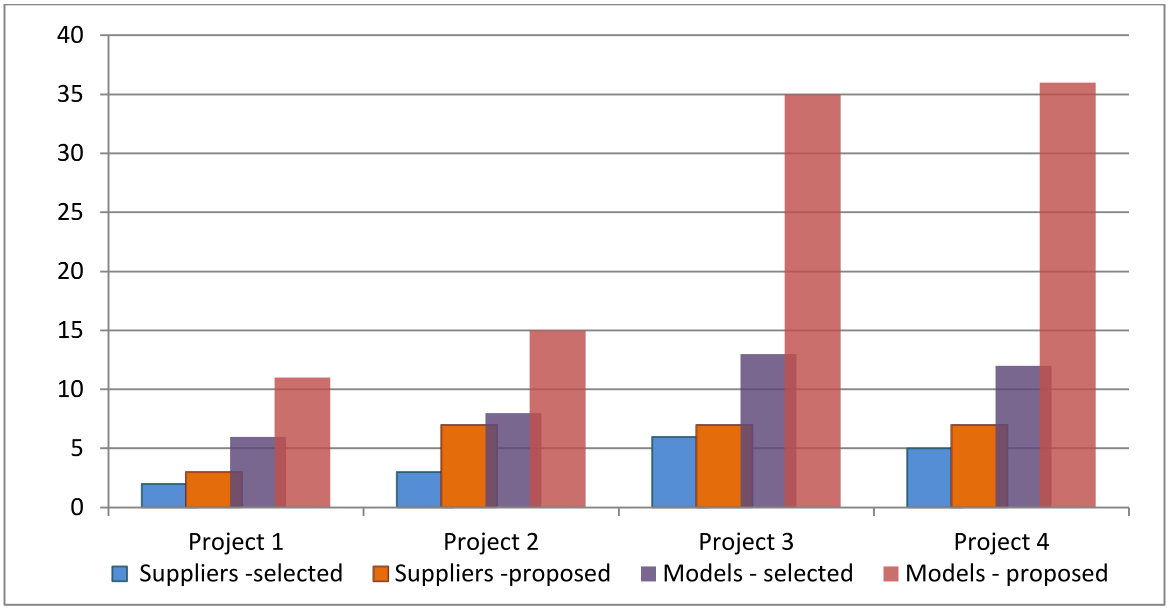
The projects of The Ministry of Energy and Water Resources to assist households, replacing inefficient appliances started at the end of 2011 and continued during the year 2012. All refrigerators that were authorized under these projects have energy rating "B" (A is most efficient).

The first project was aimed for disadvantaged population with a subsidy of 60% for replacing the old inefficient refrigerators with the new efficient ones. The refrigerator for replacement had to be in working condition, bought before 2005 and with a volume at least 300 liter. During this project, 22,245 refrigerators were replaced in less than one week.

The second and third project, of old refrigerators replacement, addressed the entire population with a subsidy of 30% subsidy. The conditions for the old refrigerator were the same as in the first project. About 50,000 refrigerators were replaced in the second project and already about 40,000 were replaced during the third and still ongoing project. In all projects the consumer had to give up his old refrigerator, to be sent to a scrapping site, authorized by the Ministry of Environmental Protection. According to the national energy efficiency program the estimated savings through the refrigerators projects, was supposed to reach 137,000,000 kWh a year. With a total of 125,000 old refrigerators replacement the estimated amount is higher and comes up to 156,250,000 kWh a year, a reduction of 114,348 tons in carbon dioxide emissions. Considering lifetime of 10 years for a refrigerator, we will have a total direct saving of 1,562,500,000 kWh.

Refrigerators Supply

Figure 2: Number of suppliers and models, by project



In order to be an authorized supplier within the projects, suppliers were required to meet a number of conditions, including low prices and low electricity consumption of refrigerator (given volume of refrigerator).

As shown in figure 2, number of suppliers has grown with projects as well as the number of models. In the first project, 2 out of 4 suppliers, and 6 out of 11 models, were approved to distribute and be distributed, under the project. In the second project, 3 suppliers and 8 models, and in the third project out of 7 suppliers and 36 models, 13 models were approved to be distributed by 6 suppliers.

The Increased number of bidders (suppliers) shows that the project is considered credible in the eyes of the population and does bring the buyers to stores.

In the year, 2012 the number of refrigerators sales reached 380,000 while in previous years the average number of refrigerators sales was 250,000. The increased number of sales, along with attractive prices, under the projects, affected the entire refrigerators market, and prices for similar refrigerators fell in about 45%. The stores raised the discounts flag on subsidized refrigerators, added more discounts for refrigerators that weren't included in the projects and offered removal and transportation as part of the deal.

In the fourth and upcoming project to replace more inefficient refrigerators for the disadvantaged famillies 13,000 refrigerators will be replaced.

Population's Participation

At the beginning of the projects the participation was high and most of the refrigerators were purchased. As shown in figure 3, the middle size refrigerators were first to sell.

Figure 3: Refrigerators sales, by month and size

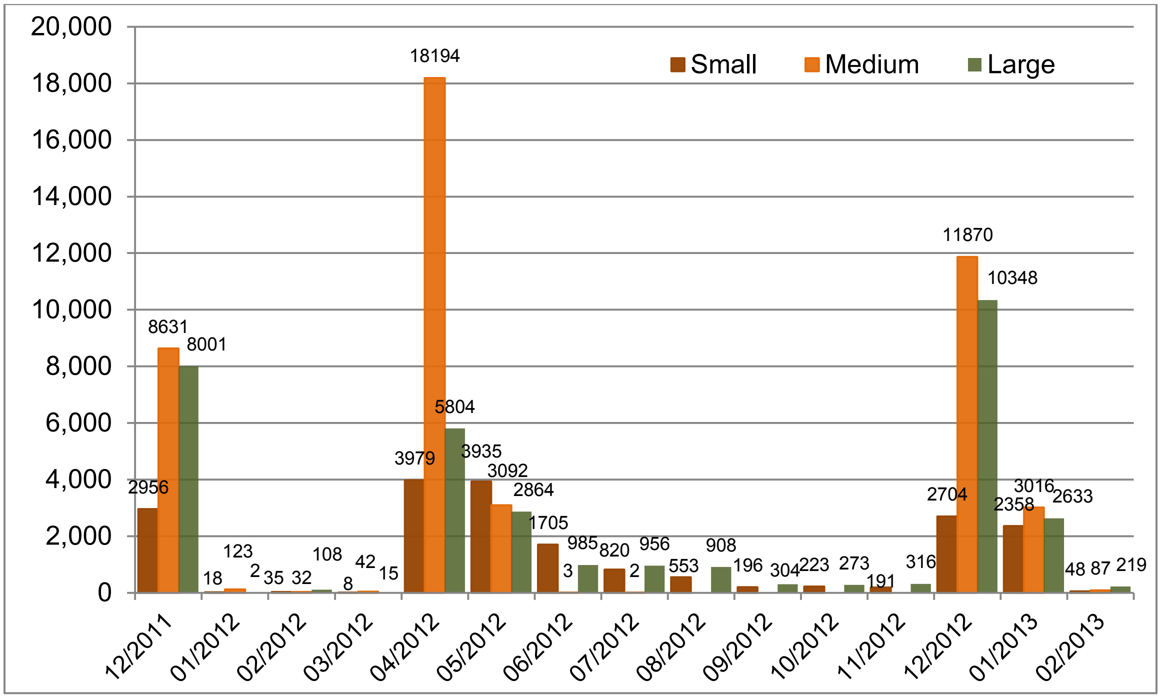
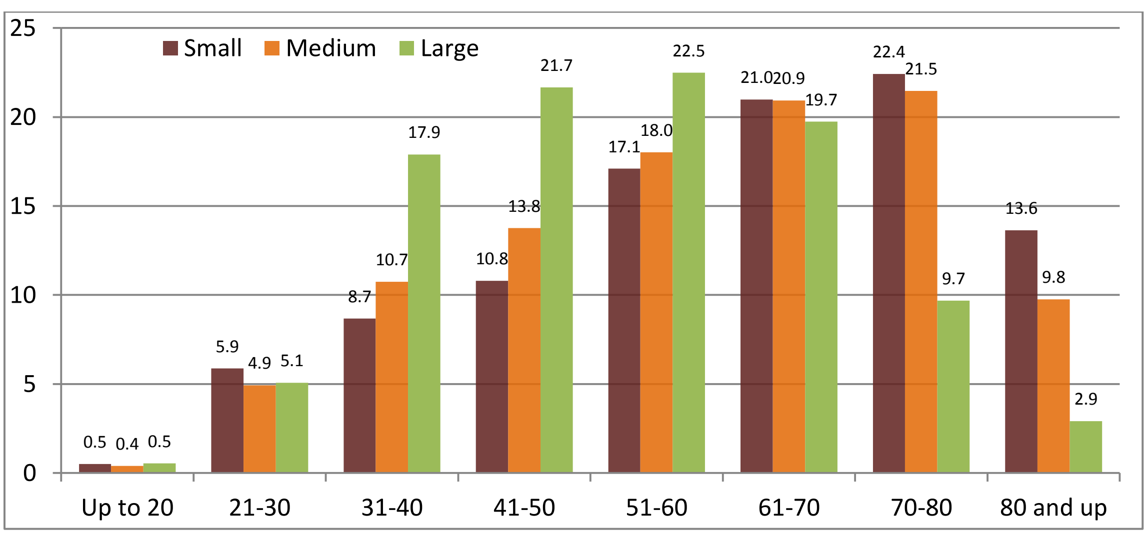


Figure 4: Refrigerators sales, by age of consumers and size of refrigerators (percent)



As shown in figure 4, up to 70 percent of the consumers, participating in the projects, were at the age of 50 years and older. Consumers ages 31-60 prefer large refrigerator, while consumers over 60 prefer the small and middle sizes.

Projects' cost

Table 3: Quantity and Government subsidy ($[1]) by population and refrigerators' size

Size group	Disadvantaged population		Entire population A		Entire population B		Total	
	Quantity	subsidy	Quantity	Subsidy	Quantity	Subsidy	Quantity	Subsidy
Small	3,029	1,089,627	12,352	2,718,418	9,247	2,197,509	24,628	6,005,554
Medium	9,077	4,521,437	21,327	5,796,475	19,434	5,235,417	9,838	15,553,329
Large	8,139	4,046,770	14,483	4,237,467	14,692	4,830,172	37,314	13,114,409
Total	20,245	9,657,834	48,162	12,752,360	43,373	12,263,098	111,780	34,673,292

Subsidy, the main component of the project cost is already 34,673,292$. Along with the cost, there are the savings that will come up to 700,483,570 NS (190,193,750$, calculated for 10 years).

Electricity Savings

Other than direct saving in electricity there are many other benefits in energy efficiency. The benefits include savings in energy and storage cost, saving water and fuel, used to produce electricity and savings in cost of emissions. Energy savings can, also, lead to a decline in demand and lower prices that can boost the economy, increase employment and energy security.

However, it is difficult to translate these benefits to money. Using energy efficient appliances, we save not only in kWh but also in other elements that are not necessarily connected to electricity.

The direct electric energy saving achieved from carrying out the projects, for a single year, comes to 117,787,719 kWh (As of June 2013).

Table 4: Savings in electricity and money, by refrigerators' size[2]

Size	Yearly saving (kWh)	Yearly saving (NS)	Yearly saving ($)
Small	27,805,320	16,535,824	4,489,770
Medium	52,163,139	31,021,419	8,422,867
Large	37,819,260	22,491,114	6,106,737
Total	117,787,719	70,048,357	19,019,375

The savings in electric energy, since 2005, are much greater, considering the new regulations along with the projects of replacing appliances.

The direct kWh savings were calculated as follow:

Saving kWh = $\sum(Co-Cni)*365$

Co – Daily consumption of old refrigerator

Cn - Daily consumption of new refrigerator

[1] According to exchange rate of 3.683, from May 31, 2013
[2] Savings were calculated according to ICE's 2013 rate for residential sector, 0.5947 ns per kWh (including VAT).

i – 1… 111,780 Refrigerators

Review of Regulations

The effectiveness of the regulations (which refer to electrical appliances used by the residential sector[3]) will be reviewed in accordance with the following parameters:

- The maximum electricity consumption required for an electric appliance according to the present regulations.
- The average electricity consumption of an electric appliance which has either been imported or manufactured in Israel during the last years.
- The average electricity consumption of new models of an electric appliance, which were authorized by the regulations during the last years.

In the near future

In the coming months several more projects will be implemented: replacement of air conditioners for the entire population; replacement of old refrigerators for disadvantaged populations and replacement of electric water heaters with solar water heaters for the entire population, as well as projects for the other sectors. Projects as chillers replacements or increasing energy efficiency will be promoted.

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[1] E. Bet Hazavdi, Drori A:State of Israel, Ministry of National infrastructures. National Energy Efficiency Program Reducing Electricity Consumption 2010 – 2020, July 2010, http://www.mni.gov.il/mni/en-US

[2] Statistical report 2010: Israel Electrical Corporation, http://www.iec.co.il/EN/IR/Documents/stat2010.pdf

[3] Statistical Abstract of Israel, Israel's Central Bureau of Statistics, http://cbs.gov.il/reader/shnatonenew_site.htm

[4] State of Israel. Energy Resources Regulation, 1998, 2004, 2008, state of Israel. (Hebrew).

[5] The Standards Institution of Israel, Standard IS 721 http://portal.sii.org.il/heb/standardization/teken/?tid=2b2f58f7-740c-4942-8609-84cacde53285

[3] Based on the content of the regulations, as it is published on the website of the Ministry of National Infrastructures.

Bottom-up scenario calculations for 10 world regions reveal worldwide efficiency potentials of about 50 % for refrigeration and washing

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Abstract

Domestic refrigerators, freezers and washing machines are among the most widely used electrical appliances all around the world. Currently, about 1.4 billion domestic cold appliances and 840 million washing machines worldwide use about 740 TWh electricity, which is more than Germany's total electricity consumption, cause CO_2eq emissions of 500 million tons and use 19 km^3 of water a year.

Although the specific electricity consumption per volume of cold appliances or per kg laundry in washing machines has decreased during recent years due to technical progress, total worldwide energy consumption of these appliances is on the increase.

In the framework of a new website "bigEE.net - Your guide to energy efficiency in buildings", which aims to provide information about technical options but also about policies to support the development of energy-efficient appliances, bottom-up scenario calculations were carried out for all 10 IPCC world regions by the Wuppertal Institute. Results show that about half of the specific energy consumption could be saved with the most energy-efficient appliances available today, and even higher savings will be possible with next generation technologies by 2030. According to the model, these savings are usually very cost-effective. The scenario results and policy strategies to address these potentials will be presented in this paper.

Introduction

Domestic refrigerators, freezers and washing machines are among the most widely used electrical appliances in the residential sector all around the world, contributing significantly by their electricity consumption to the greenhouse effect. Therefore political instruments focus on the introduction of labels, minimum energy performance standards (MEPS) or subsidies in order to improve the efficiency of appliances on the market. In addition, washing machines are related to water consumption, which could cause problems in regions of the world with drinking water shortages.

This raises the question of how high the worldwide electricity and water consumption of household appliances in the different regions of the world is today and how the number of devices and their consumption per unit and so their total consumption for cold appliances and washing machines will develop in the future in the business as usual case.

It is well known from international appliances databases like "Topten" (www.topten.info), which present the most efficient appliances worldwide, that significant differences in consumption between the average and the most efficient appliances exist. Based on this, the questions arise, what is the saving potential if only the most efficient appliances are purchased and what kind of policies and policy instruments are required for such a market transformation.

Distribution of current worldwide electricity and water consumption of domestic cold appliances and washing machines

Distribution of current worldwide electricity consumption of domestic cold appliances

Country specific bottom-up analysis – based on several sources[1] all around the world – shows that currently 1.4 billion refrigerators, fridge freezers and freezers are in use in households. The average electricity consumption of these cold appliances amounts to about 450 kWh per year and appliance. With an annual total electricity consumption of 650 TWh, they account for almost 14 % of the electricity consumption of the residential sector and cause worldwide annual greenhouse gas emissions of 440 million tons of CO_2eq.

Thereby, the distribution of domestic cold appliances varies widely between the different world regions. In North America (NAM), Western Europe (WEU) and Pacific OECD (PAO) about 1.7 people own one cold appliance, whereas in other world regions the level of ownership is still well below saturation (see figure 1). This is expected to change significantly in the future, especially due to the booming markets in Asia (CLASP / LBNL 2007).

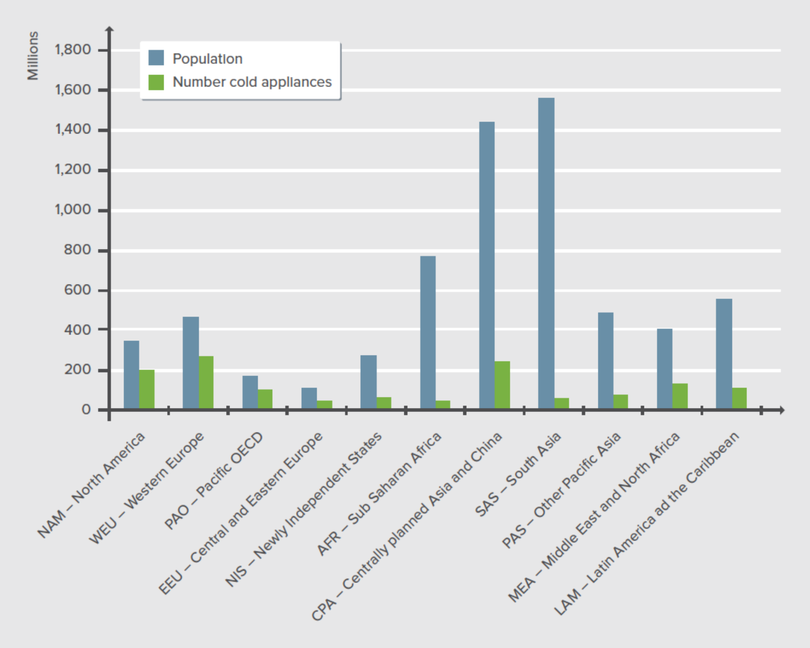

Figure 1: World population and number of cold appliances in the different world regions according to IPCC systematic in 2010. (Reference: Own calculation based on WEC 2009, IEA 2010 and other reports)

The worldwide uneven distribution of domestic cold appliances as well as their different size and efficiency levels lead to large differences in electricity consumption of this group of appliances in different world regions.

Distribution of current worldwide electricity and water consumption of domestic washing machines

The country specific bottom-up analysis for washing machines[2] shows that about 840 million domestic washing machines are in use worldwide. The average annual consumption of each of these washing

1 IEA 2010, WEC 2009, Department of the Environment, Water, Heritage and the Arts 2008, Hollanda 2010, Schaeffer 2008, Vendrusculo 2008, Natural Resources Canada 2010, Fridley 2007, 2008, Lin 2006, Lu 2006, Bertoldi 2006, Ademe 2009, Presutto 2007, Qader 2009, Hagan 2006, The World Bank 2006, 2008, 2009, De la Rue du Can 2009, Letschert 2007, Murakami 2009, Cabanas 2009, WECS 2010, Ministry of Economic Development 2010, Foran 2010, DOE 2009

2 Based on data by Pakula / Stamminger (2010) and other available reports (e.g. AATCC 2011, ACEEE 2011, Berkholz et al. 2006, Biermayer / Lin 2004, Faberi et al. 2007, GfK 2011, Josephy et al. 2011, RECS 2009, IEA-4E 2011)

machines amounts to about 110 kWh of electricity and 23 m^3 of water. With an electricity consumption of 92 TWh per year, they account for about 2 % of the total electricity consumption of the residential sector worldwide. Annually, washing machines also consume about 19 billion m^3 of water and cause worldwide greenhouse gas emissions of 62 million tons of CO_2eq.

Thereby, the distribution of domestic washing machines is very uneven between different world regions. In the world regions NAM, WEU and PAO, on average 2.9 to 4.4 people own one washing machine (see Figure 2). In other world regions the level of ownership is still well below saturation. For example in Sub Saharan Africa (AFR), there is on average one washing machine per 125 persons. However, this is also expected to change significantly in the future, especially in the booming markets in Asia (CLASP / LBNL 2007).

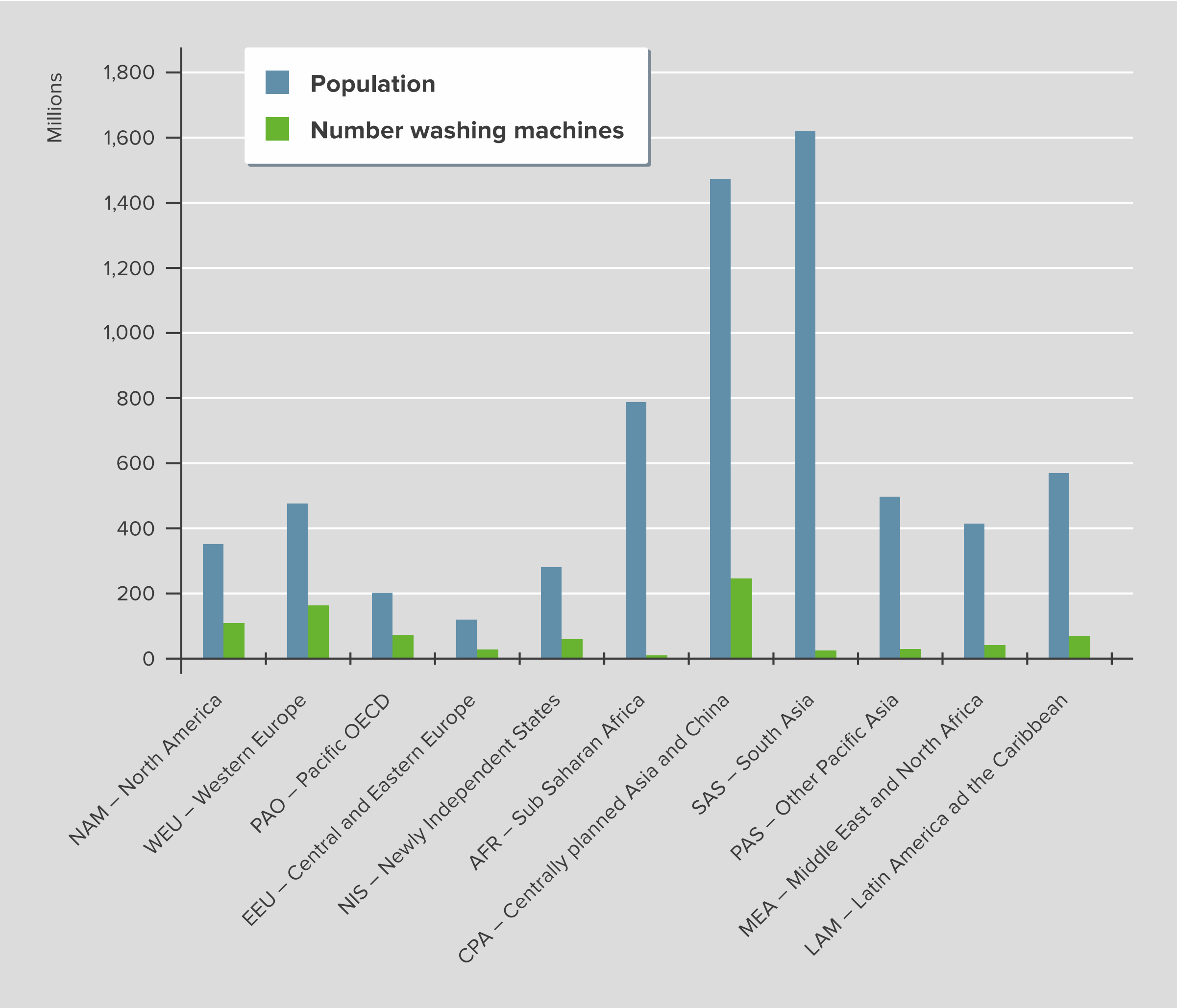

Figure 2: World population and number of washing machines in the different world regions according to IPCC systematic in 2010 (Reference: Own calculation based on IEA, Pakula / Stamminger (2010) and other reports)

The uneven distribution of domestic washing machines worldwide, different types of machines (different technologies like horizontal and vertical axis washing machines) and their various efficiency levels, as well as different wash habits and practices (e.g. wash temperatures, number of wash cycles per year) lead to substantial disparities in electricity and water consumption within the different world regions.

Types of automatic washing machines, main features and geographical distribution

While the technology for refrigerators, fridge freezers and freezers does not vary significantly worldwide, domestic washing machines can be assigned to two different main categories:

- Horizontal axis machines

In horizontal axis machines (Figure 3), only the bottom of the washtub is filled with water. Compared to vertical axis machines, significantly less water per wash cycle is used. Horizontal axis machines are commonly equipped with an internal electric water heating system. Hence, the energy consumption heavily depends on the chosen washing temperature. Modern washing machines with horizontal axis technology have an automatic load sensing function in order to reduce water and electricity consumption in response to consumer loads that are smaller than the rated capacity. Horizontal axis machines are gaining market shares in almost all markets worldwide (Pakula / Stamminger 2010).

Figure 3: Horizontal axis washing machine, front loader configuration. Source: iStockphoto (2013)

- Vertical axis machines

Traditionally, the tub of vertical axis machines (Figure 4) is entirely filled with water. Although most modern vertical axis machines also have automatic water level settings or the user can set the water level manually, even present-day machines often consume about twice as much water per wash cycle as horizontal axis machines. Vertical axis machines are usually not equipped with an integrated electric water heating system, but warm washes can be done by using hot water from external sources. This additional energy needed to heat up water from the tap is hard to estimate, because it can be done by electricity or other energy sources like gas, coal, oil or solar power (Pakula / Stamminger 2010). Vertical axis machines are still most widespread in America, Australia and Asia.

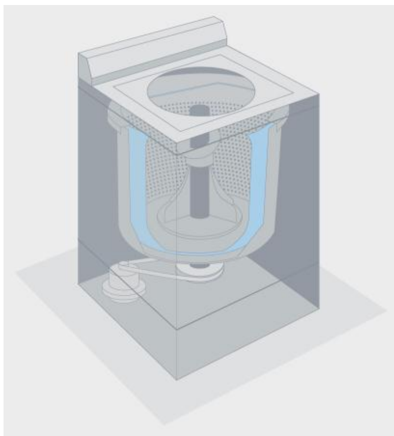

Figure 4: Vertical axis washing machine (Agitator type). Source: own illustration (www.bigee.net 2013)

Within these two basic categories, appliances vary in their configurations and the range of options. The most common types of automatic washing machines worldwide are:

Horizontal axis, front- or top loading washing machine (also known as "front-loader" or "drum type" machines).

These machines show large energy- and water savings when comparing most efficient to inefficient average models on the market, especially in Europe as such washing machines are most popular in this region. Additionally, the share of horizontal axis machines is also steadily rising in most other markets worldwide. Switching from vertical axis to horizontal axis machines offers another important water and energy saving potential, because horizontal axis machines usually consume significantly less (pre-)heated water per wash cycle than vertical axis machines.

In a horizontal axis washing machine, the textiles are placed in a horizontal drum and partially immersed in the washing water. The mechanical action is provided by the rotation of the drum about its axis. The drum is accessible from one single door on the front (front-loader configuration) or from several adjacent doors on the top of the machine and the drum (top-loader configuration). Many traditional horizontal axis machines have a minimum program temperature of 30°C, which means that these machines use electricity to heat up water even in the coldest program selectable (Pakula / Stamminger 2010). Since the introduction of high efficient low-temperature detergents, many contemporary washing machines have been equipped with 20°C, 15°C and “cold wash” programs to reduce the energy consumption significantly.

Horizontal axis drum type washing machines are used mainly in WEU/EEU, and increasingly in most other markets (Pakula / Stamminger 2010).

Vertical axis, top loading agitator washing machines

This type of washing machines shows large energy- and water savings compared to inefficient models on the market, especially in North- and Latin America, as such washing machines are popular in these regions. If cold water is used, the energy consumption per wash cycle is low. But although the majority of washing machines in North America are vertical axis machines without internal heating system, the average washing temperature is reported to be at about 30°C, which causes an electricity consumption of about 0.43 kWh per wash cycle (Pakula / Stamminger 2010). This might include warm water from the tap and thus energy from external resources, which are hard to quantify.

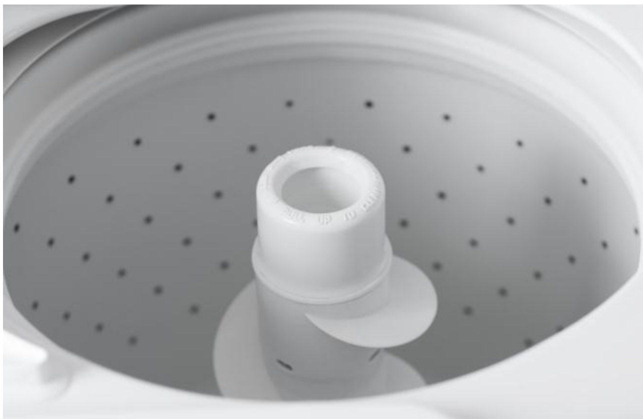

Figure 5: Vertical axis washing machine, agitator. Source: iStockphoto (2013)

Vertical axis, top loading impeller washing machines

These machines show large energy- and water savings compared to inefficient models on the market, especially in Asia (China, South Korea, Japan) and Australia as such washing machines are popular in these regions. The mechanical swirl-action is produced by a device, which is named by most manufacturers as ‘impeller’, rotating about its axis (Figure 5). During operation, the uppermost point of this device is substantially below the minimum water level (Faberi et al. 2007). This type of washing machines is traditionally designed as top-loading device (accessible from one single door on the top). If cold water is used, the energy consumption per wash cycle is low. However, although vertical axis impeller machines are usually not equipped with an internal water heating system, the usage of preheated water from external sources through a separate hot water inlet is commonly possible and is often reported (Pakula / Stamminger 2010).

Figure 6: Vertical axis ‘high-efficiency’ washing machine, Impeller, Source: iStockphoto (2013)

Occasionally, impeller-type washing machines are also referred to as “high efficient washers” (especially in North America) due to an improved washing process and a reduced water usage compared to inefficient agitator-type models. Nevertheless, a higher usage of bleach and other detergents, as well as washing treatments with relevant amounts of water and energy outside the washing machine may indicate only a mediocre level of washing performance provided also by these machines.

Techno-economical saving potentials

Description of the model calculations

The bottom-up model used for the purposes of this paper is a simplified version of the DEESY Stock Model developed by the Wuppertal Institute, which assesses scenarios with focus on energy and water consumption as well as costs[3]. According to the development of the stock volume[4] and the typical lifetime of an appliance (15 years for cold appliances and washing machines), the model calculates the per-annum market volume for each year of the covered scenario time period (2010 to 2030), including the first-time acquisition as well as the replacement of end-of-life appliances. The techno-economical characteristics of the typical product purchased in a certain year are dependent on the Base Case and Best Available Technology (BAT) available at the time of purchase and on a weighting factor reflecting the level of energy efficiency for the respective scenario. Future BAT technology, named BNAT (best not yet available technology), is becoming more efficient in terms of electricity and water consumption each year and is regarded in the model as well as additional costs for these product improvements. The modelling of the historical appliance stock purchased within the 15 years in advance of the covered scenario time period (1995 to 2009) is essentially based on the same methodology. However, the development of these preceding years is additionally calibrated for the base year (2010) to meet the expected stock volume in this year[5].

In order to assess the techno-economical saving potential of the most efficient appliances, subsequently two scenarios are compared: a Baseline[6] scenario, in which Base Case products have 100 % market share after 2010, and an Energy Efficiency scenario, assuming a 100 % market share of BAT products. The characteristics of the Base Case and BAT products are based on the country specific bottom-up analysis, which was performed as preparatory work for the modelling. Account has been taken to different regional economic and market specific conditions. Consequently, the savings in terms of energy, water and costs depend on the year and the world region considered respectively.

Results for domestic cold appliances

As the results from the model calculations show, large efficiency improvements can be achieved globally if the most energy-efficient appliances available on the market are systematically purchased instead of standard technologies. Despite the expected 27 % increase of the worldwide cold appliance stock in use by 2020 and the 62 % increase by 2030, the annual electricity consumption of domestic cold appliances could be reduced from 650 TWh in 2010 to 475 TWh by 2020 and to about 400 TWh by 2030 (see Figure 7) with the best available technologies on the market. The potential would be even larger and achieved faster if old and inefficient cold appliances would be replaced and recycled before they have reached the end of their technical lifetime.

The analysis also shows that the electricity consumption of domestic cold appliances per unit varies very much between the different world regions. As this consumption is not proportional to the typical appliances size in the respective region it can only be explained by different efficiencies.

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[3] For more information on the DEESY stock-based bottom-up accounting model see ECN (2011)

[4] Future stock volume (2020, 2030) based on CLASP PAMS2007 model (CLASP / LBNL 2007)

[5] Existing stock volume of domestic cold appliances in 2010 is based on own elaboration by Wuppertal Institute.

[6] The baseline scenario assumes a moderate efficiency improvement according to historical trends

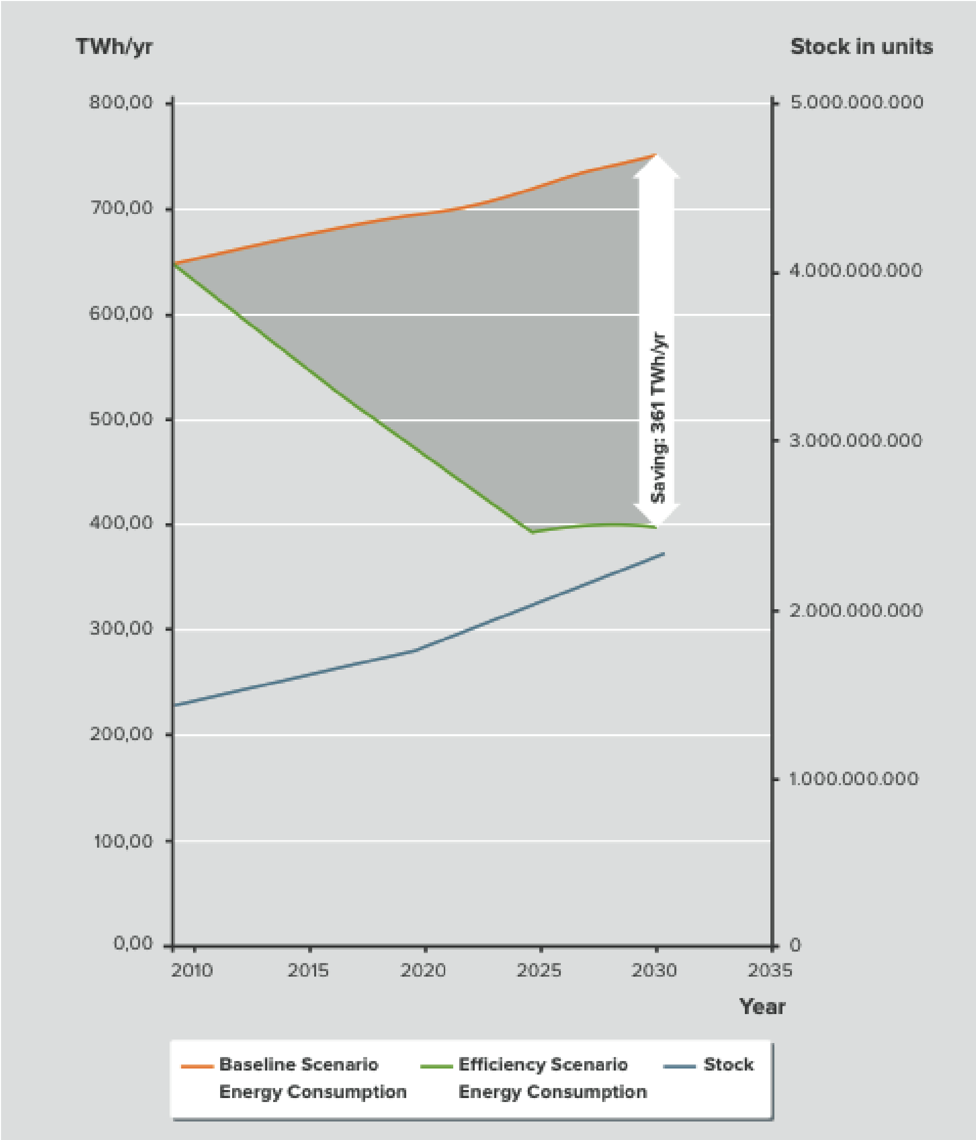

Figure 7: Development of the worldwide domestic cold appliances stock 2010-2030 and the total electricity consumption in the Baseline Scenario versus the Efficiency (BAT) Scenario. Source: own calculation; WEC 2009 and IEA 2010 for current electricity consumption and population data

World regions	**Present situation**		**Results of model calculations for 2030**			
	Stock number domestic cold appliances [m]	Electricity consumption [TWh/year]	Stock number domestic cold appliances [m]	Baseline Scenario electricity consumption [TWh/year]	Efficiency Scenario electricity consumption [TWh/year]	Electricity savings Efficiency Scenario vs. Baseline Scenario
NAM	209	123.3	265	117.7	62.0	47 %
WEU / EEU	335	126.3	411	111.1	59.1	47 %

PAO	108	48.6	137	49.6	28.0	44 %
NIS	69	28.5	125	39.2	17.8	54 %
AFR	49	20.4	107	33.7	18.1	46 %
CPA	260	108.3	570	179.7	96.5	46 %
SAS	63	40.2	138	54.5	29.4	46 %
PAS	82	31.8	148	48.1	29.2	39 %
MEA	142	60.4	256	80.9	43.5	46 %
LAM	118	61.6	175	60.2	30.1	50 %
Total	**1,435**	**649.4**	**2,332**	**774.8**	**413.8**	**47 %**

If every time a domestic cold appliance is purchased in the efficiency scenario, the most efficient model is chosen instead of a standard model, 240 TWh of electricity and 158 million tons of CO_2-eq can be saved per year in 2020. Moreover, in 2030, even 360 TWh of electricity and 235 million tons of CO_2-eq can be saved per year. Based on the assumptions of the performed model calculation[7], over the whole lifetime of the energy-efficient refrigerators and freezers purchased until 2030, the total economic benefit (discounted) is 193 billion EUR[8] for end-user perspective and 105 billion EUR for societal perspective. However, the actually achievable savings are dependent on varying investment costs and electricity prices in the different world regions. For example, the incremental investment costs for BAT could be very low in countries where already high efficiency standards are established and high where no market and no manufacturer of efficient cold appliances exist.

Therefore, regionally optimized policy measures and programs have to address this technical efficiency improvement potential under consideration of cost-effectiveness for society as well as for end-users.

Results for washing machines

In order to assess the techno-economical saving potential of the most energy and water efficient washing machines, an identical approach to the domestic cold appliances has been followed. This also includes a comprehensive country specific bottom-up analysis and the same two-scenario comparison based on a typical lifetime of 15 years for washing machines.

As the results from the model calculations show, large efficiency improvements can be achieved globally if the most energy and water efficient washing machines available on the market are systematically purchased instead of standard technologies. By this means, a relative decoupling of the growth of the worldwide annual energy and water consumption and the increasing stock of domestic washing machines can be achieved. While the stock is expected to grow by 36 % until 2020, in the efficiency scenario the energy consumption would only increase by 12 % and the water consumption by 5 %. Although the stock is expected to grow by another 26 % until 2030, the increase of the energy and water consumption would be limited to half of that value (13 %), each for energy as well as water consumption (see Figure 8 and Figure 9). Thereby, higher living standards, represented by increasing appliance ownership rates, a more frequent usage of warm wash cycles as well as a technological change towards more water efficient horizontal axis washing machines already have

[7] Presuming an average worldwide electricity price for all world regions.

[8] For the purposes of the model calculation, all monetary figures are provided in EUR 2010

been anticipated. In contrast, in the baseline scenario, the energy and water consumption would increase by 43 % and 15 % by 2020 and additionally by 35 % and 18 % by 2030.

If every time a washing machine is purchased, the most energy- and water-efficient model is chosen instead of a standard model, 31.5 TWh of electricity, 2.2 billion m^3 and 20.8 million tons of CO_2-eq can be saved per year in 2020. Moreover, in 2030, even 65 TWh of electricity, 3.6 billion m^3 of water and 42.4 million tons of CO_2-eq can be saved per year.

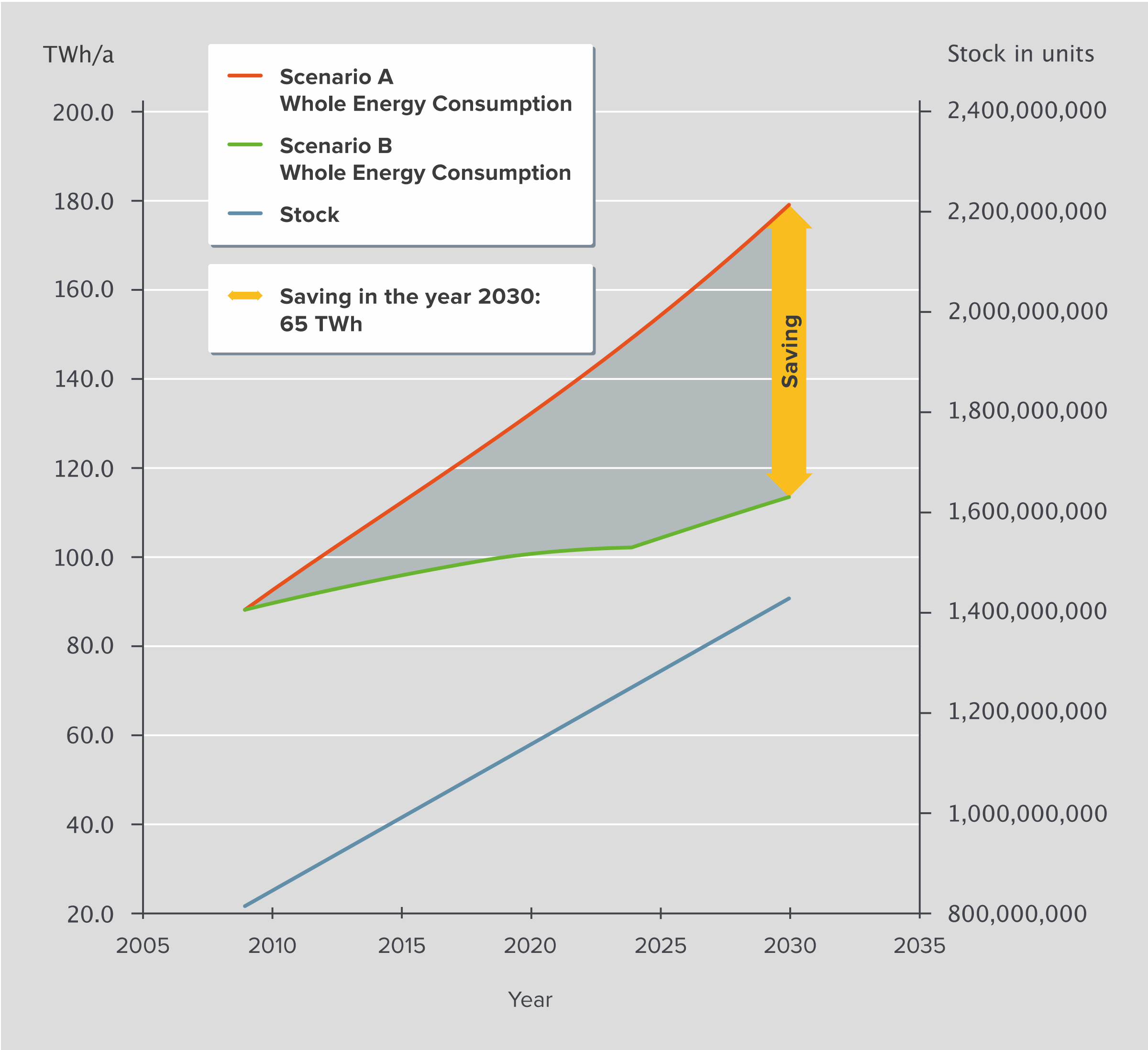

Figure 8: Total electricity consumption of domestic washing machines, Baseline Scenario compared to the Efficiency Scenario (Source: own calculation; WEC 2009 and IEA 2010 for current electricity consumption and population data)

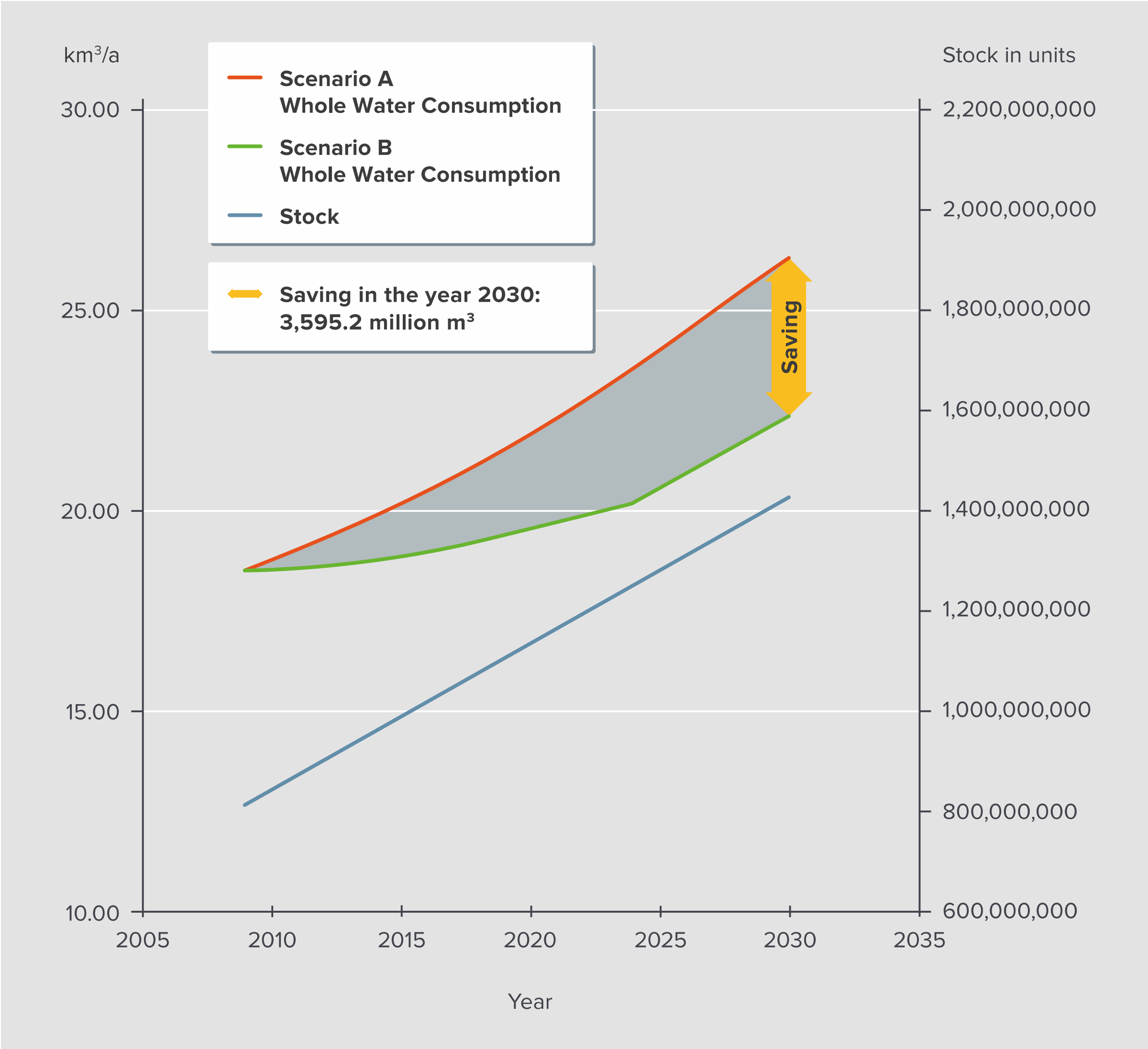

Figure 9: Total water consumption of domestic washing machines, Baseline Scenario compared to the Efficiency Scenario (Source: own calculation; WEC 2009 and IEA 2010 for population data)

World regions	**Present situation**		**Results of model calculations for 2030**			
	Stock number domestic washing machines [m]	Electricity consumption [TWh/year]	Stock number domestic washing machines [m]	Baseline Scenario electricity consumptio n [TWh/year]	Efficiency Scenario electricity consumptio n [TWh/year]	Electricity savings Efficiency Scenario vs. Baseline Scenario
AFR	6.4	1.3	19.9	2.63	1.78	32.2%
CPA	247.4	7.4	462.0	67.65	34.46	49.1%
LAM	69.2	5.6	124.3	9.35	7.24	22.6%

MEA	38.5	9.3	70.5	13.69	9.51	30.6%
NAM	106.8	15.9	148.6	18.87	14.56	22.8%
NIS	58.3	11.3	65.2	8.64	5.91	31.6%
PAO	71.0	6.1	85.7	7.48	5.48	26.8%
PAS	28.4	2.7	70.9	7.25	4.80	33.8%
SAS	20.7	1.6	151.0	13.61	8.31	38.9%
WEU / EEU	192.9	31.0	239.8	29.11	21.21	27.1%
Total	**839.6**	**92.2**	**1,437.9**	**178.3**	**113.3**	**36.5%**

World regions	**Present situation**		**Results of model calculations for 2030**			
	Stock number domestic washing machines [m]	Water consumption [km^3/year]	Stock number domestic washing machines [m]	Baseline Scenario water consumption [km^3/year]	Efficiency Scenario water consumption [km^3/year]	Water savings Efficiency Scenario vs. Baseline Scenario
AFR	6.4	0.2	19.9	0.47	0.41	13%
CPA	247.4	3.3	462.0	5.16	4.02	22%
LAM	69.2	2.4	124.3	3.12	2.79	11%
MEA	38.5	1.1	70.5	1.19	1.04	12%
NAM	106.8	3.9	148.6	3.62	3.29	9%
NIS	58.3	0.7	65.2	0.56	0.49	12%
PAO	71.0	3.5	85.7	2.88	2.74	5%
PAS	28.4	1.0	70.9	1.62	1.42	12%
SAS	20.7	1.0	151.0	5.49	4.56	17%
WEU_EEU	192.9	2.0	239.8	1.94	1.69	13%
Total	**839.6**	**19.1**	**1,437.9**	**26.0**	**22.4**	**14%**

Policy strategies to address the potentials

The previous section has illustrated the possible energy savings of refrigerators and washing machines worldwide and in different world regions. This means that energy efficient appliances can bring large energy savings, while providing the same or better service. The energy efficiency efforts do not only achieve high energy saving potentials. CO_2 emissions can also be reduced cost-effectively from a life-cycle perspective and thus provide economic benefits. Furthermore, several other co-benefits like energy security, health and increased competitiveness can be realised. By offering innovative products this can open up new (niche) markets, which will likely have a positive effect on the economy as a whole. Co-benefits increase social and/or individual welfare and come as a free add-on to the direct benefits of energy efficiency for investors.

However, there are still lots of inefficient appliances available on the market and market forces alone are often unlikely to bring a very high energy-efficient market development about (Sorrel et al. 2004; Thomas 2007). There are various barriers to manufacture, sell or buy energy efficient products that hinder a market transformation towards energy efficiency. All elements and levels of the appliances value chain have their own and specific characteristics. Financial, knowledge and technical barriers as well as lack of interest and the investor-user dilemma are some of the major reasons why there is a gap between the saving potentials and the energy savings actually realised by markets alone (Thomas 2006; IEA 2008).

Policy is needed to overcome these respective barriers and to exploit the existing potentials. Policy-makers have to intervene and develop adequate strategies to change this market development. The overall goal for policy makers should be to move the market towards to the best available technology and perspectively to the best not yet available technology (BNAT) with very high energy efficiency levels. Almost half of the energy saving potential could be achieved from the worldwide adoption of the most stringent energy efficiency regulations. Furthermore there are lots of energy efficiency technologies, which are already far beyond existing regulations, so the other half of the potential lies in reaching this “best practice” level. This emphasises that energy efficiency policy is incomplete. Even in economies that already have policies requiring or promoting high energy efficiency levels, significant savings are possible. Where requirements are limited, the savings from accelerated adoption of leading policies would stimulate much larger savings (Wuppertal Institute 2012).

Therefore, it is highly advisable for policy makers all over the world to pay attention to the large potentials and to energy efficiency improvements. It is important to abandon the prevailing approach of ‘as-fast-and-as-cheap-as-possible’ because it will be wasting vast amounts of energy and money throughout their lifetime. To tap this tremendous potential, appropriate and integrated packages of policies and measures are necessary, supporting very efficient appliances.

The first step is to pay attention to every actor in the value chain. By knowing the barriers and incentives of each type of actor, the policy package can be adapted to guarantee desired results and achieve the greatest possible energy savings. In order to be able to adequately design and implement energy efficiency policies and measures, political decision makers must have good knowledge of the concerned market actors and thoroughly analyse the specific incentives and barriers faced by each of them. These market actors are for instance manufactures, whole sales, retailers, investors and users. All of these actors make decisions that can influence the energy performance of appliances in question.

The second step concerns the following question: How can the incentives that market actors have be strengthened, and how can the barriers be overcome. Experience from pro-active countries and an analysis of market barriers show that several instruments need to interact and reinforce each other in a comprehensive policy package (cf. next box). Every policy measure is tailored to overcome one or a few of the mentioned market barriers, but none can address all these barriers (Tholen & Thomas 2011). The impact of well-combined policies is often synergistic i.e. the impact of two or more instruments is often larger than the sum of the individual expected impact. Therefore different policies addressing the demand- and supply side of markets should be properly combined according to regional circumstances. As pro-active countries have demonstrated, a comprehensive and coherent policy package for energy efficiency will usually provide a sound balance between clear ambitious mandatory measures, incentives, information and capacity building. It also needs a governance framework to enable implementation of these policies.

This governance framework includes a concrete and ambitious roadmap, an organisation to design, implement and monitor the policy (like an energy agency), and an independent test procedure. Furthermore a compliance system, and financial mechanisms such as Energy Saving Obligations and Energy Efficiency Funds to realise a successful implementation of specific policies in this package are needed. These specific policies are the following:

Legal provisions on minimum energy performance standards (MEPS) reduce search and transaction costs and partly overcome the investor-user dilemma. They are a cost-effective way to eliminate the segment of the worst energy-performing products from the market. However, they do not harness additional savings potentials due the most energy-efficient products in such cases. Therefore, appliance standards are often combined with labelling and rebates in order to give incentives for investments beyond the level required by the MEPS. Financial or other incentives can give the decisive push that makes people opt for the more energy-efficient investments. In addition, financing instruments such as soft loans can be needed to overcome potential incremental costs for BAT products and to enable investors to make more sustainable upfront investments.

To pull the market even more into an energy efficient direction, information programmes, trainings for sales staff and manufacturers, and especially procurement programmes can influence the market to promote energy efficient appliances. With procurement programmes but also with bulk purchasing projects and competitions it is even possible to go beyond the best available technology and to support a market development towards BNAT with very high energy-efficiency levels.

This general description of a comprehensive policy package should be adapted to national circumstances and to specific appliances. Each appliance and each market has its own specificity and the barriers as well as incentives for the market transformation are also diverse. Therefore the package must be adapted to specific circumstances of single product groups. For examples refrigerators have several specialities like the high energy and cost saving potentials as well as many differing technical characteristics (volume and additional features like climate class, built-in appliance, free-standing freezer, ‘no-frost’ function, etc). Policy makers should pay attention to all these factors and create policy packages that reach the desired results.

The next box shows how China has implemented an overall policy package to influence the market development of refrigerators and freezers. In some areas China is very successful with its policy package and is on a good way to promote energy efficiency.

China achieved a substantial transformation towards higher energy efficiency in the refrigerator market using a policy package adapted to its national conditions. Along with the rapid economic growth of the country in recent years, the sales figures of appliances also increased. The sales figures of top-rated energy-efficient refrigerators skyrocketed from 360,000 to 46 million units in nine years (from 1999 to 2008). In light of this development, it must be a top priority to the government to phase out the production of the least efficient products while promoting sales of highly efficient ones. Population size and increasing prosperity make China a highly attractive market for appliance manufacturers. This makes energy efficiency policies in the country even more important as policies can have huge impacts on greenhouse gas (GHG) levels. Moreover, China is regarded as the world’s workbench. Thus, policy makers can implement regulation targeting the production process of appliances directly. Due to this situation the Chinese government introduced a comprehensive policy package to increase the energy efficiency of appliances.

The 11th Five-Year plan (FYP) was established in 2005 and aimed at reducing energy intensity by 20% up to 2010. For the exemplary product group refrigerators, this meant that their average energy-efficiency indicator was to be reduced to between 62% and 50% by 2010, meaning they would be in the two most energy-efficient classes of the energy label (Zhou et al. 2010, p6442). According to results mentioned in the National 12th Five Year Plan, the actually achieved energy conservation and GHG emission reduction was 49%. The 12th Five-Year plan for 2011 to 2015 targets a total energy and carbon intensity reduction by 17%.

China has committed to achieving these goals through different measures. There has been a minimum energy performance standard (MEPS) since 1990 in order to eliminate very inefficient models from the market. The standards are mandatory, but compliance is sill a big issue and needs to be targeted (Zhou 2010). In addition to this MEPS regulation a mandatory comparative energy labelling system (CELS) was established in 2005. The label is based on the coloured arrows design of the European Union’s appliance energy label. However, it uses number 1 to 5 instead of characters A to G. The rating goes from grade 1, which counts for refrigerators having an energy consumption of at most 55% of the MEPS and goes over grade 2: 55-65%, grade 3: 65-80%, grade 4: 80-90%, to grade 5: 90-100%. The mandatory label uses the MEPS as a reference point for the thresholds. Refrigerators not meeting the MEPS will not be labelled, nor even produced (Fridley 2008, p. 6 f). This mandatory label provides market transparency on the energy efficiency of appliances to consumers.

Furthermore, China introduced a voluntary endorsement label, and refrigerators will only be provided with it, if they have an energy performance of at least a grade 2 level of the energy information label. To inform the consumers about the labels and energy efficiency in general several information and education campaigns were implemented. The energy efficiency information week takes place annually and focuses on different themes. A consumer education programme has focused on awareness raising towards energy efficient refrigerator advantages and the willingness of purchasing them. Assistance was also granted to engineers from refrigerator manufacturers who received training in international technology options. The international organisation, Top10 China, establishes an internet-based platform to provide independent and up-to-date information on the best available energy efficient products in the Chinese market.

The Chinese government also established a law obliging state agencies and organisations to purchase only energy-efficient appliances. The “Energy Efficient Products For Government Procurement” law tries to raise awareness of higher standards and the benefits of purchasing energy efficient appliances by setting a good example to the people. A series of energy efficiency appliance lists have been submitted by the Ministry of Finance and the National Development and Reform Commission (NDRC), where all appliances covered by that scheme are listed (State Council Office 2007).

Moreover, in 2012, the Ministry of Finance (MoF) has launched a financial incentive programme offering grants for the purchase of energy saving refrigerators (and other appliances) of up to 70-400 Yuan depending on the product size. Consumers receive the subsidies immediately at the retailers. Funding, which totals 26.5 billion yuan (~3.3 billion EUR), has been provided for the period from June 2012 until May 2013.

Conclusion

Within the bigEE project, an extensive data gathering was carried out for domestic cold appliances and washing machines worldwide as well as a modeling work, in order to assess the saving potentials in terms of energy, water, GHG emissions and costs. The results show between 2010 and 2030 a stock increase of more than 60 % worldwide for cold appliances and of about 70 % for washing machines. Consequently, in the baseline scenario, which already includes a moderate efficiency improvement, the electricity consumption is to be expected to rise by 20 % for cold appliances. For washing machines, even an increase of 93 % for electricity and 36 % for the water consumption is expected.

However the modeling has also shown that with existing (BAT) and coming (BNAT) technologies, it is almost possible to halve worldwide electricity demand for both, residential cold appliances and washing machines in comparison to this baseline in year 2030. In the efficiency scenario absolute reductions are possible for cold appliances in all regions, even in developing and emerging regions such as CPA with China, where the stock is expected at least to double within 20 years. One additional outcome of this study is that these electricity savings are cost-effective both for end-users and society.

However, this market transformation towards energy efficient appliances is unlikely to happen itself, therefore policy packages are needed. Within the bigEE-project a new theoretical and empirical foundation has been developed that shows what is a necessary and advisable package of policies for energy efficiency in appliances.

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Measuring Electric Energy Efficiency in Portuguese Households: a tool for energy policy

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Abstract: There is a great interest in measuring the efficiency of energy use in households, and this is an area where EDP has done research in both data collection and methodology. This paper reports on a survey of electric energy use in Portuguese households, and reviews and extends the analysis of how efficiently households use electrical energy. In addition, we compare the stratified cross-section analysis with a time-series study to extend our understanding of how to measure energy efficiency.

It is relatively common to model energy efficiency in terms of an energy intensity or electricity intensity relationship with aggregate income or aggregate consumption. A new approach to this problem was suggested by Filippini and Hunt (Energy Economics 2012) [1] in which an econometric energy demand model was estimated to control for the exogenous variables determining the energy demand. The variation in energy efficiency over time and space could then be estimated by applying econometric efficiency analysis to determine the variation in energy efficiency. In this paper we apply this approach to the Portuguese electricity sector in particular. The analysis allows the identification of priority areas for the implementation of measures to enhance electricity efficiency. On the other hand, it is also possible to evaluate the success of the energy efficiency measures, which have been launched by Government and the Regulator, in the recent past.

Keywords: Electric Energy Efficiency, households, econometric efficiency analysis

Introduction and Contribution of this Paper

EDP Serviço Universal has carried out a structured interview and survey of about 3500 Portuguese households that asked about appliance ownership, family income and family size. The sample was stratified by region, subscribed demand categories (kVA) and actual electric energy consumption bands (kWh). The appliance ownership covered space heating/cooling, refrigeration, cooking and washing, and the survey applied to ownership levels in 2008, before the recent economic crisis dominated economic decision making, allowing the sample findings to be relevant to the long term. The survey complemented earlier surveys of the same variables. These data can be used to model the electric energy efficiency of the households in the Portuguese mainland.

The aim of this paper is to show the results from the application of an econometric approach to evaluate energy efficiency to this cross-section data set. The fact that the survey was conducted in 2008 means that the results are illustrative of the analysis that could now be updated with more recent surveys, as consumers' behaviour may have changed in the recent past. The same method

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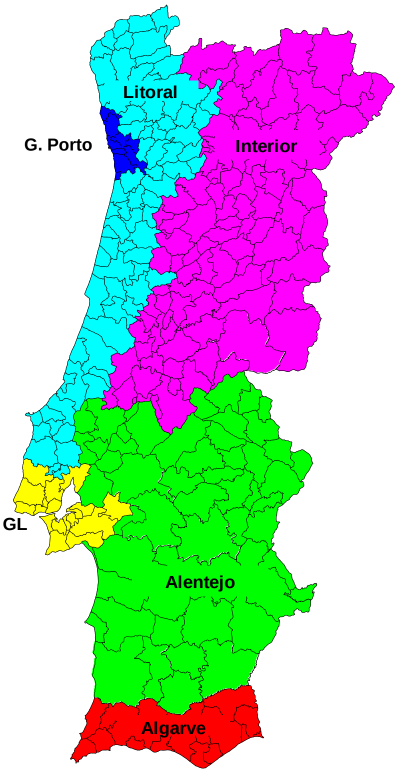
was applied to a time series data set also collected by EDP on electric energy use in households in Portugal.

This new approach is based on a recent study by Filippini & Hunt (2012) [3] on energy efficiency within the European Union. The paper begins with a review of the datasets collected by EDP, and then moves on to the different ways in which these can be modelled to understand energy efficiency amongst households in Portugal, according to region and subscribed demand, and also over time.

Data sample 1: cross section study of EDP customers in 2008

The first cross section sample, which was collated from interviews with household customers, was based on EDP consumption data for 2006, and it was stratified by region, subscribed demand categories (kVA) and actual electric energy consumption bands (kWh). The following figure illustrates the sample distribution. Interviews took place during 2008.



Region	Subscribed demand kVA	Population Total	Population <500 kWh	Population >=500 <1500 kWh	Population >=1500 <3000 kWh	Population >=3000 kWh	Interviews
Alentejo	≤ 3,45	244 744	49 879	68 969	83 330	42 566	326
Alentejo	]3,45 ; 6,95]	80 848	6 151	11 289	22 000	41 408	111
Alentejo	]6,95 ; 10,35]	10 808	744	1 286	2 333	6 445	60
Alentejo	]10,35 ; 13,80]	3 939	181	287	531	2 940	138
Alentejo	]13,80 ; 20,70]	4 312	115	211	420	3 566	90
Alentejo	> 20,70	204	4	4	5	191	20
Total Alentejo		**344 855**	**57 074**	**82 046**	**108 619**	**97 116**	**745**
Algarve	≤ 3,45	148 421	40 008	48 392	41 820	18 201	184
Algarve	]3,45 ; 6,95]	88 613	14 621	22 902	24 178	26 912	81
Algarve	]6,95 ; 10,35]	12 827	1 255	2 439	3 035	6 098	46
Algarve	]10,35 ; 13,80]	6 942	368	713	1 147	4 714	70
Algarve	]13,80 ; 20,70]	9 310	241	520	907	7 642	59
Algarve	> 20,70	556	4	10	15	527	17
Total Algarve		**266 669**	**56 497**	**74 976**	**71 102**	**64 094**	**457**
Grande Lisboa	≤ 3,45	815 056	107 382	275 793	316 970	114 911	212
Grande Lisboa	]3,45 ; 6,95]	298 057	20 358	51 847	105 544	120 308	114
Grande Lisboa	]6,95 ; 10,35]	60 025	3 755	7 954	15 973	32 343	63
Grande Lisboa	]10,35 ; 13,80]	13 937	502	1 011	2 343	10 081	119
Grande Lisboa	]13,80 ; 20,70]	17 097	416	780	1 733	14 168	98
Grande Lisboa	> 20,70	1 012	10	18	28	956	52
Total Grande Lisboa		**1 205 184**	**132 423**	**337 403**	**442 591**	**292 767**	**658**
Grande Porto	≤ 3,45	172 803	32 752	45 146	55 272	39 633	86
Grande Porto	]3,45 ; 6,95]	241 191	16 170	36 493	74 380	114 148	151
Grande Porto	]6,95 ; 10,35]	69 212	3 381	5 576	13 036	47 219	61
Grande Porto	]10,35 ; 13,80]	17 918	548	854	1 733	14 783	116
Grande Porto	]13,80 ; 20,70]	7 747	147	270	405	6 925	116
Grande Porto	> 20,70	541	3	8	10	520	32
Total Grande Porto		**509 412**	**53 001**	**88 347**	**144 836**	**223 228**	**562**
Interior	≤ 3,45	555 564	183 880	162 148	153 503	56 033	206
Interior	]3,45 ; 6,95]	155 055	20 969	26 402	43 950	63 734	71
Interior	]6,95 ; 10,35]	20 985	1 899	3 008	4 992	11 086	73
Interior	]10,35 ; 13,80]	5 306	245	465	885	3 711	58
Interior	]13,80 ; 20,70]	5 749	214	349	617	4 569	46
Interior	> 20,70	143		4	5	134	15
Total Interior		**742 802**	**207 207**	**192 376**	**203 952**	**139 267**	**469**
Litoral	≤ 3,45	789 875	173 382	215 155	266 426	134 912	176
Litoral	]3,45 ; 6,95]	390 595	37 630	62 055	119 143	171 767	173
Litoral	]6,95 ; 10,35]	85 817	5 430	8 755	19 718	51 914	94
Litoral	]10,35 ; 13,80]	22 065	748	1 396	2 758	17 163	43
Litoral	]13,80 ; 20,70]	17 969	415	578	1 266	15 710	58
Litoral	> 20,70	835	10	11	11	803	41
Total Litoral		**1 307 156**	**217 615**	**287 950**	**409 322**	**392 269**	**585**
Total	**≤ 3,45**	**2 726 463**	**587 283**	**815 603**	**917 321**	**406 256**	**1 190**
Total	**]3,45 ; 6,95]**	**1 254 359**	**115 899**	**210 988**	**389 195**	**538 277**	**701**
Total	**]6,95 ; 10,35]**	**259 674**	**16 464**	**29 018**	**59 087**	**155 105**	**397**
Total	**]10,35 ; 13,80]**	**70 107**	**2 592**	**4 726**	**9 397**	**53 392**	**544**
Total	**]13,80 ; 20,70]**	**62 184**	**1 548**	**2 708**	**5 348**	**52 580**	**467**
Total	**> 20,70**	**3 291**	**31**	**55**	**74**	**3 131**	**177**
Total		**4 376 078**	**723 817**	**1 063 098**	**1 380 422**	**1 208 741**	**3 476**

Figure 1: Overall number of customers (population) and sample stratification

The data collected includes information on appliance ownership per region and for each selected group of subscribed demand. The following graphs exhibit the same data broken down according to family income and family size. This information is relevant for demand forecasting purposes, as it gives an idea of the saturation levels for the ownership rates in the different appliances. In the case of dishwashing machines, for instance, the rate of ownership of the highest income class (84%) may be used as a proxy for the saturation level, whereas only 40% of the households in the highest income group have clothes´ driers; the comparison with the average (58% and 27%, respectively) shows the potential increase for these appliances. The data also shows that, despite the fact that bigger families tend to have more appliances, families with more than four persons have lower rates of ownership of appliances like the dishwahing machine or electric oven and stove, possibly due to income constraints. The opposite is true for freezers.

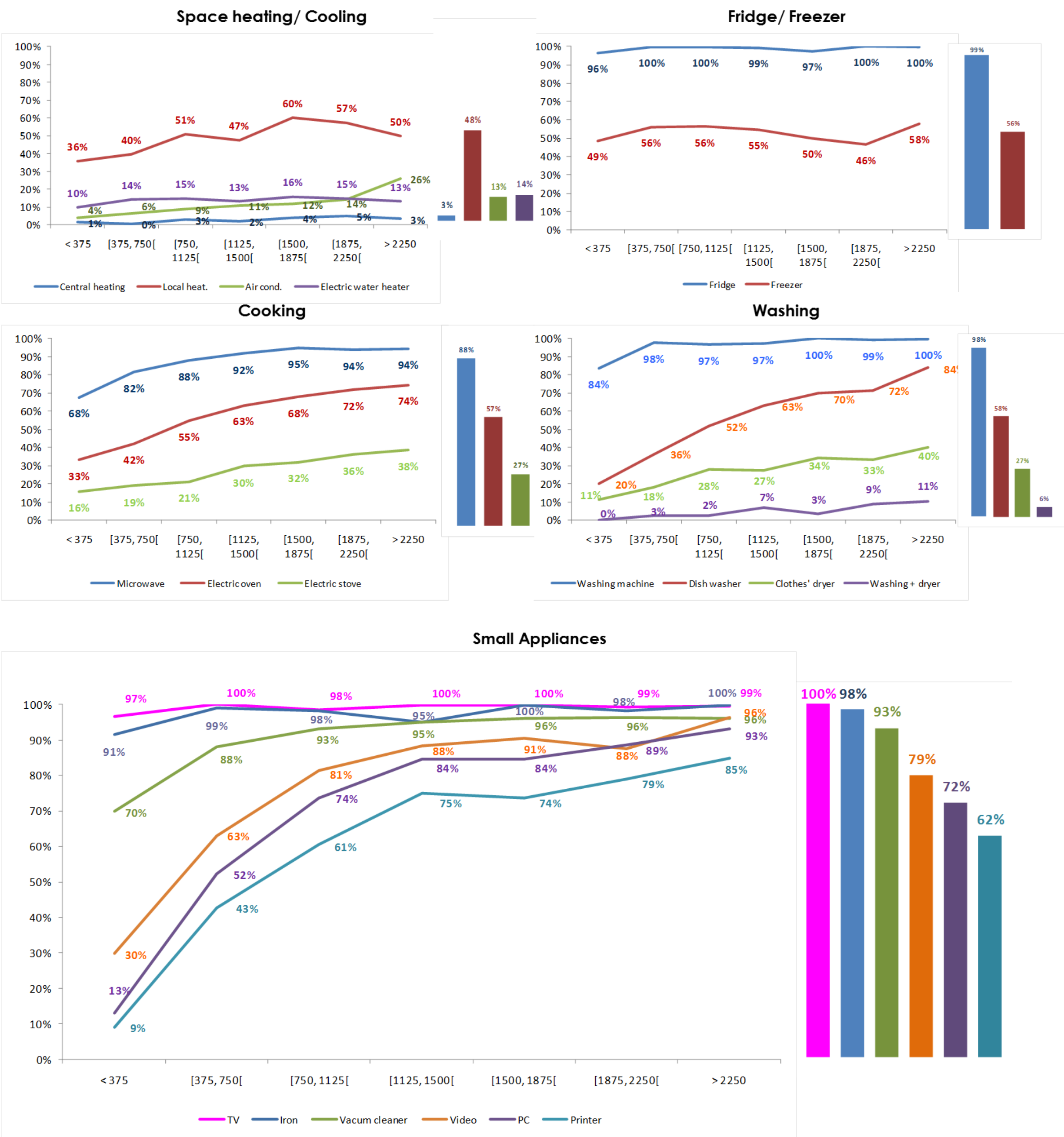


Figure 2: Ownership Rates vs. Family Income

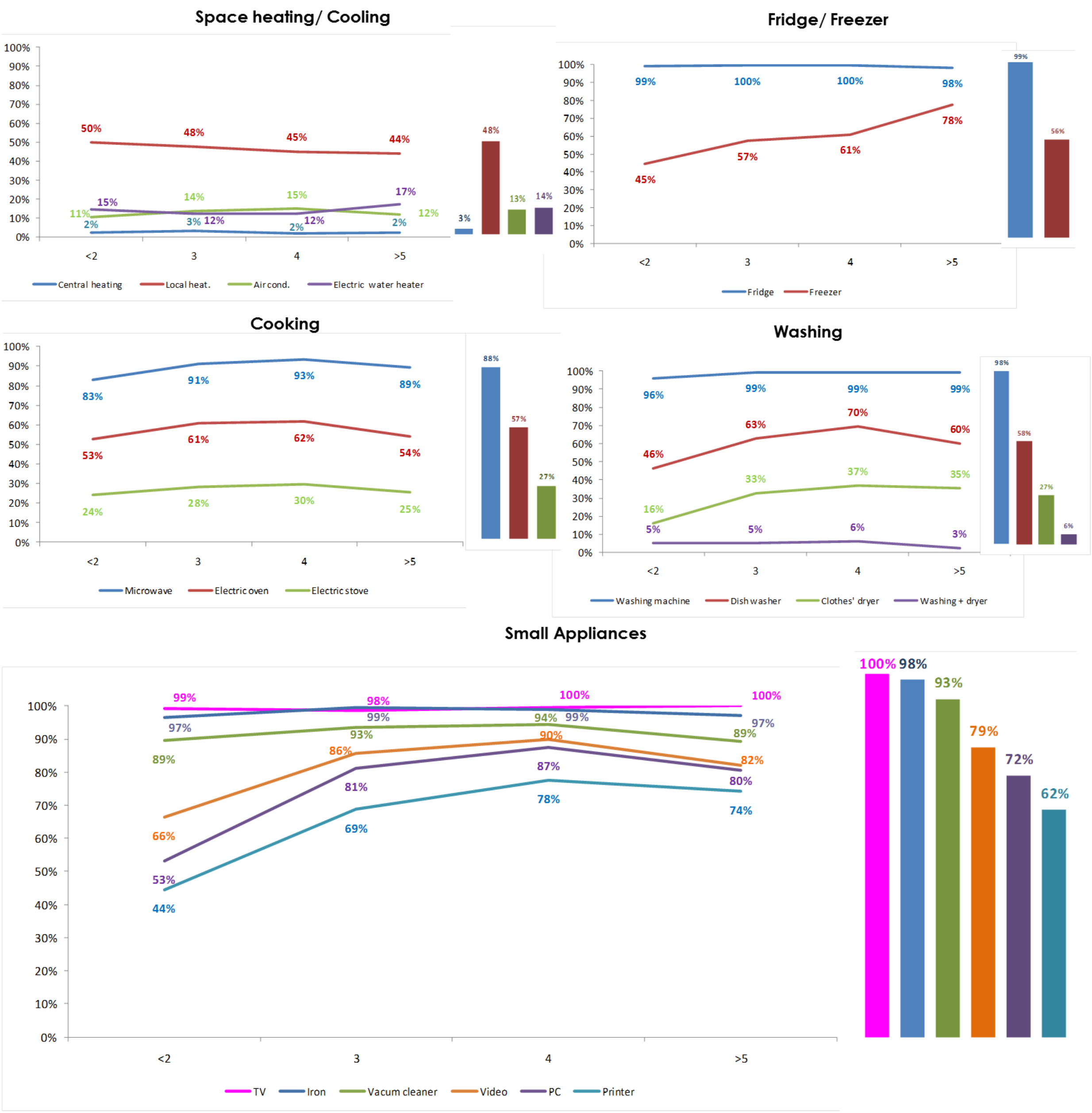


Figure 3: Ownership Rates According to Family Size

Turning now to the efficiency analysis, we have selected the following variables:

- Household Electricity Consumption (y);
- Clients (for electricity consumption), i. e. the number of customers (x_1);Family Income (x_2);
- Additional variable to explain inefficiency: electric Heating ownership/ electric water heating ownership

The following graphs illustrate how household electricity consumption varies across regions/ subscribed demand bands with the variation in clients and family income. Band 6, marked in red, exhibits a slightly different behaviour, as the number of consumers in this band is lower, but consumption is relatively higher; this fact is taken into account through a dummy variable (the intercept moves upwards):

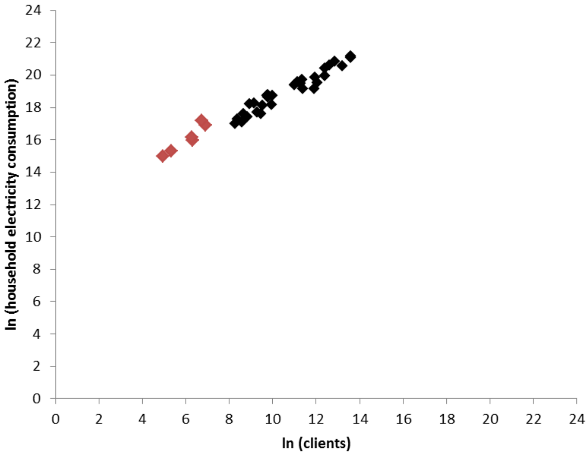


Figure 4: Household Electricity Consumption versus Clients

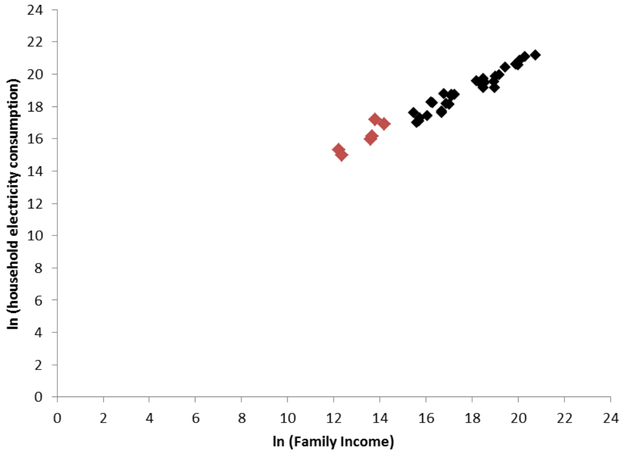


Figure 5: Household Electricity Consumption versus Family Income

Econometric Modelling of Energy Efficiency

It is relatively common to model energy efficiency in terms of an energy intensity or electricity intensity relationship with aggregate income or aggregate consumption. A new approach to this problem was suggested by Filippini and Hunt (*Energy Economics* 2012) [1] in which an econometric energy demand model was estimated to control for the exogenous variables determining the energy demand. The variation in energy efficiency over time and space could then be estimated by applying econometric efficiency analysis to determine the variation in energy efficiency.

Energy efficiency is conventionally measured by the ratio of energy consumption (E) to a measure of aggregate national income or expenditure (Y), i.e. energy intensity is:

E/Y = energy consumption relative to income

However, this measure is too simple because other variables (Z) and random errors impact on the measured intensity, and therefore the efficiency relationship itself varies over time:

E = f(Y, Z, efficiency, errors)

Filippini & Hunt (2012) [1] suggested a regression model (to be precise the model of stochastic frontier analysis, SFA) of this relationship which includes two components in the error term:

E = f(Y, Z) + u + v

In this relationship we identify two types of error:

- u = inefficiency;
- v = measurement, specification, sampling error

The kernel relationship: f(Y, Z) however must be specified parametrically.

Therefore we can measure a stochastic demand frontier to judge energy efficiency, and a schematic representation of this is given in the figure 6 below.

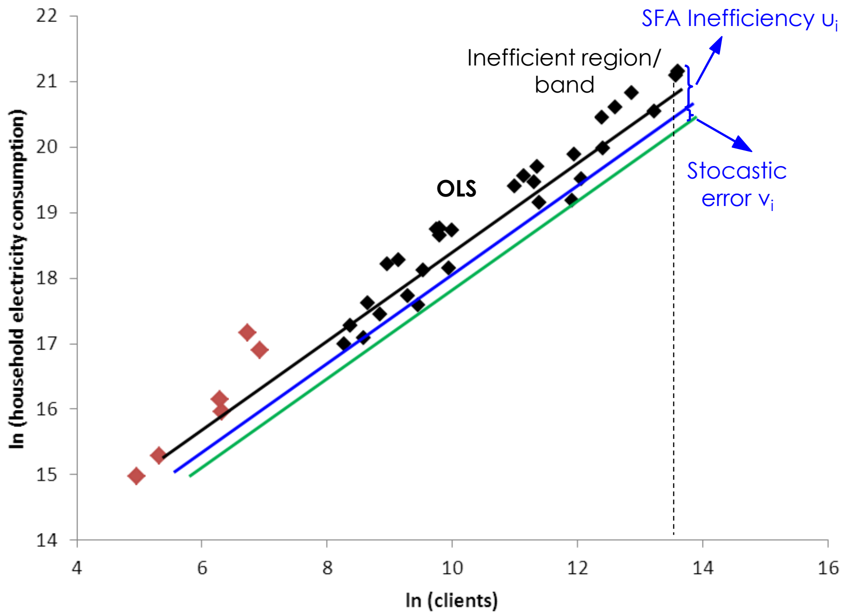


Figure 6: SFA model of energy intensity: inefficiency u_i stochastic error v_i

Formally, we write ln y_i as the dependent variable and we let X_i represent the explanatory variables. The remaining variation in the dependent variable is due to a composite error term comprising inefficiency (u_i) and idiosyncratic error (v_i).

SFA Model: $\ln y_i = a + bX_i + u_i + v_i$

Composite error term

A measure for the presence or contribution of inefficiency is then derived from the variances of the error components

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$$

We can interpret this parameter as follows:

$\gamma = 0$: no inefficiency, while $\gamma = 1$: errors are exclusively related with inefficiency.

Having fitted the regression model, we identify three curves in figure 6. The highest curve represents the average relationship amongst the variables, while the lowest curve represents the efficient frontier that relates minimum household energy use to the number of clients. The lowest curve is the frontier if there is no stochastic error in our data. Allowing for a stochastic error component means the efficient frontier is the intermediate curve, and it is the distance to this curve which is used to measure efficiency of energy use. We begin our analysis therefore by fitting this model to the cross-section data on household consumption.

Electric Energy Efficiency in Households – cross-section sample

A Technical Effects model was adopted, in which additional variables are introduced as explanatory variables of the error term, and the distribution of inefficiency includes a constant (truncated) [4] [5].

Parametric kernel of the behavioural relationship: $\ln E_i = \alpha + \beta_1 \ln FI_i + \beta_2 NC_i + \beta_3 D + u_i + v_i$

Assumed probability distributions for the inefficiency and error terms: $u_i \sim \left|N\left(\mu_i, \sigma_u^2\right)\right| \; v_i \sim N\left(0, \sigma_v^2\right)$

Assumed model for how Z-variables affect the average inefficiency: $\mu_i = \delta_0 + \mathbf{Z}_i'\boldsymbol{\delta} \quad \forall\, i = 1 \ldots n$

Where:

E = Electricity Household Consumption

FI = family income;

NC = number of clients;

D = 1 for band 6 (subscribed demand > 20.7 kVA), D = 0 otherwise;

Z-variables = determinants of the inefficiency, including electric heating and electric water heating ownership

The results of fitting three different versions of this model which allow for different Z-variables to determine the inefficiency are shown in table 1 below with the significance codes for the probability-values associated with each coefficient.

Table 1: Results for the stochastic frontier analysis of electric energy consumption

	model 1		model 2		model 3	
Intercept	-0.791	****	-0.595		8.482	****
family income	0.762	****	0.762	****	0.356	*
clients					0.388	*
band 6 clients	0.627	***	0.538	**	0,577	*
Z-Intercept	0.256		0.444		-0,610	
Z-electric heating ownership	0.842				1.204	
Z-electric water heating ownership			0.155			
sigmaSq	0.120	****	0.117		0.097	***
gamma	1.000	****	0.712		0.008	
mean efficiency:	0.529		0.624		0.969	

Significance codes: 0 '****' 0.001 '***' 0.01 '**' 0.025 '*'

From these results, we conclude as follows: there is a strong positive relationship of energy consumption with family income and the relationship does shift for band 6 consumers. There is significant variation in energy efficiency in consumption patterns across the different regions averaging about 60 per cent. Electric heating and water heating increase the inefficiency but not in a statistically significant way.

Including also the number of clients as an explanatory variable, we find that the level of efficiency of the households shows a major improvement — mean efficiency increases to 96.9%. This result highlights the importance of using more than one explanatory variable to determine efficiency, which is one of the advantages of this method, in comparison with the simple energy intensity measurement, as referred above.

The Figures below illustrate the resulting measured performance of energy efficiency across region/ subscribed demand.

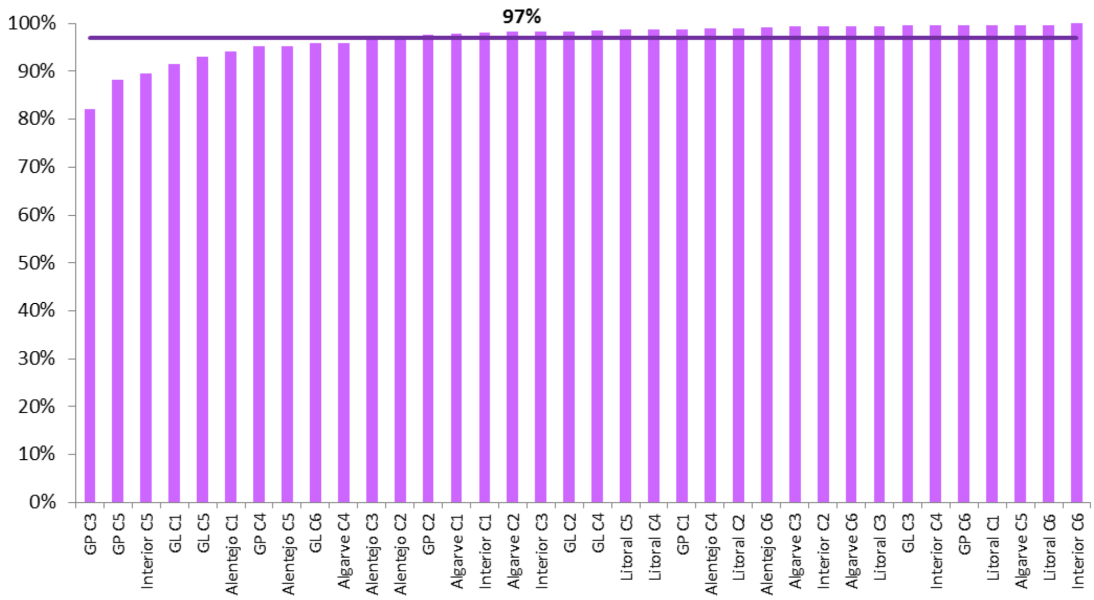


Figure 7: Electric Energy Efficiency Results

Dependent Variable: ln Household Electricity Consumption

Independent Variables: ln Family Income, ln Number of Clients, Dummy for band 6

Additional variable to explain inefficiency: Electric Heating ownership

In summary, the results from this survey lead to the conclusion that priority regions to reduce inefficiency in electricity consumption are Greater Porto, Greater Lisbon and Alentejo. Litoral is the most efficient region. The additional information included in figure 8, relating to consumption per client, shows that the regions with higher consumption per client are not necessarily the less efficient, reflecting the importance of the additional explanatory variables.

Residential clients included in the band between 13.8 and 20.7 kVA of subscribed demand should also be considered as the main target for the promotion of electric energy efficiency measures.

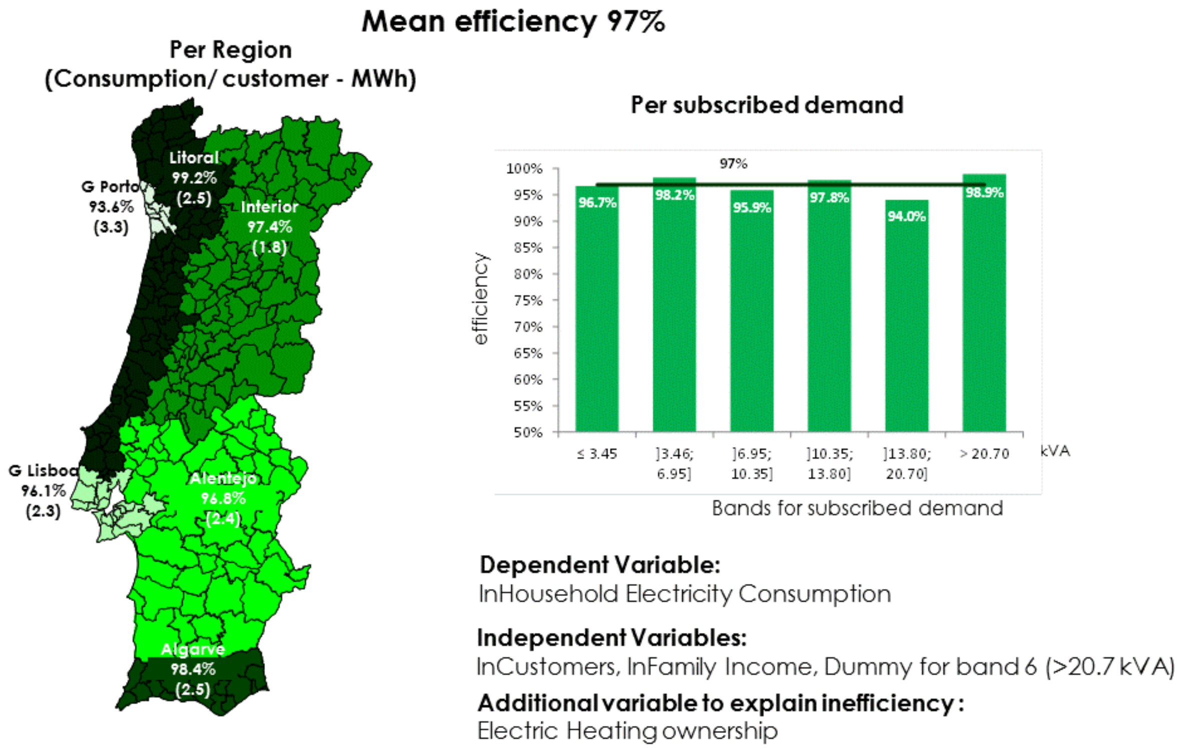


Figure 8: Electric Energy Efficiency per region according to 6 bands for subscribed demand

Extending the Data Set

Having established that energy efficiency does vary across different regions and population groups, we now consider how it has varied through time for the household sector in the whole of the Portuguese mainland. The data are for 1970-2011 and forecasts for 2012-2015 [3] [2].

From amongst these additional yearly data collected by EDP, we select for initial analysis the following variables, to which we fitted a stochastic frontier analysis as we did with the cross-section data:

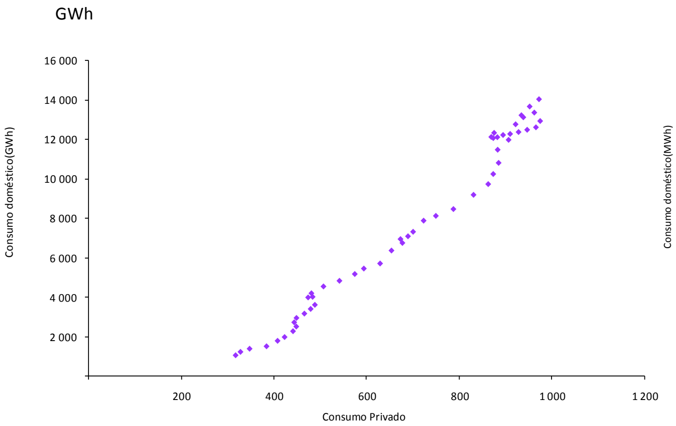
Household Electricity Consumption (y)

Private Consumption (of all goods and services) (x_1)

Consumers for electricity consumption (x_2)

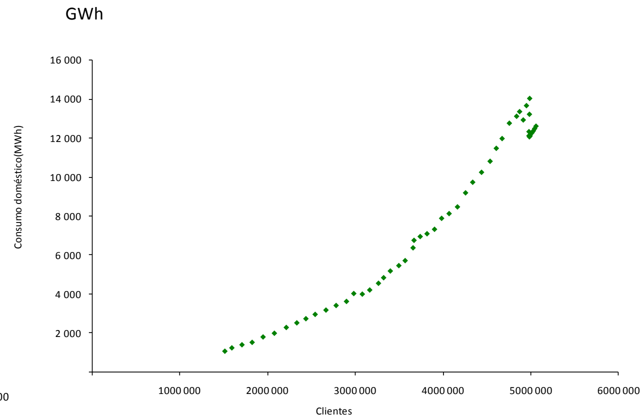
The following graphs, figures 9 and 10, illustrate how household electricity consumption varies over time with the variation in x_1 and x_2.

[2] Part of these results was presented at the 4th Workshop on Efficiency and Productivity Analysis, Porto, 29th of October 2012.



Private Consumption

Figure 9: Household Electricity Consumption versus Private Consumption



Consumers

Figure 10: Household Electricity Consumption versus Consumers

Source: Forecasts based on a model for Household electricity consumption developed by Pedro M. Martins and Júlia Boucinha (EDP).

Electric Energy Efficiency in Households – SFA model

The behavioural relationship is an Error Component function estimated through Maximum Likelihood as we illustrated previously for the cross section sample.

Dependent Variable: ln Household Electricity Consumption

Independent Variables: ln Private Consumption, ln Consumers

The sample consists of Aggregate residential electricity consumption in the Portuguese mainland over the period 1970-2011. Results are shown in the table below.

	coefficient	standard-error	t-ratio
constant	-11.30	0.42	-27.01
lnPrivate Consumption	0.69	0.05	12.96
lnConsumers	1.49	0.05	30.14
gamma	0.925	0.07	13.03
Log likelihood function	98.54		
LR	2.23		

Table 2: results for the stochastic frontier analysis of electric energy consumption

In the following figure we illustrate the resulting trend in the measured performance of energy efficiency over time, showing that electric energy efficiency in households has fallen in the recent past. The introduction of a weather correction in the last few years leads to an increase in the efficiency levels, except in 2007 and 2008, when the mild weather conditions led to a reduction in electricity demand, whereas in the remaining years, from 2003 onwards, the temperature effects led to an increase in electricity consumption and, hence, an apparent reduction in efficiency.

Current forecasts for household electricity consumption are consistent with an increase in efficiency (99% in 2014-2015).

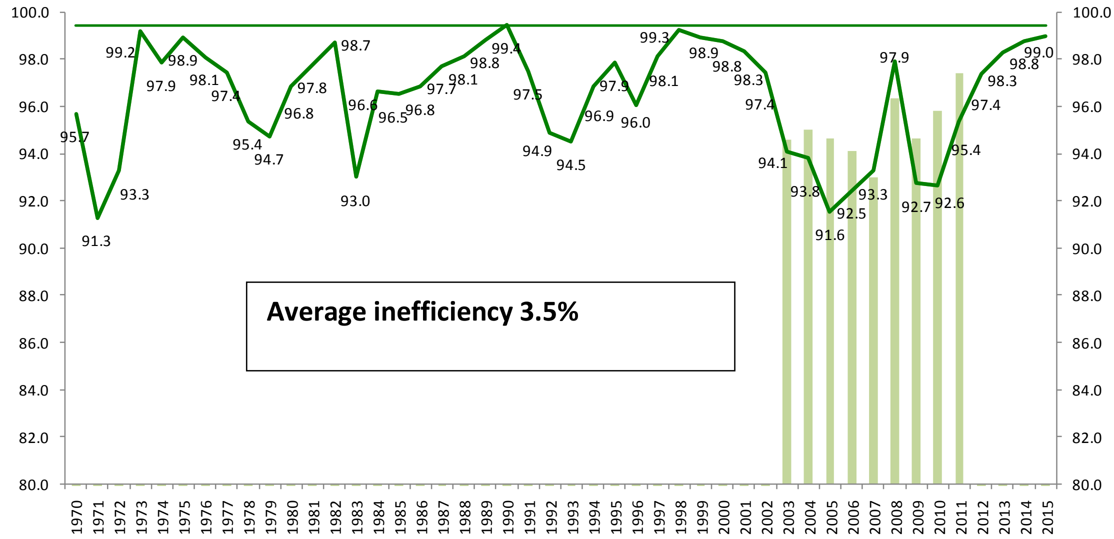


Figure 11: Electric Energy Efficiency Trend in Portuguese Households (%) - (1970-2015)

Dependent Variable: ln Household Electricity Consumption

Independent Variables: ln Consumers, ln Private Consumption

Corrected for weather effects: 2003-2008 REN; 2009-2011 – estimates by J. J. Domingos and J. Boucinha

According to our estimates for the period 2008-12, expected savings from energy efficiency initiatives, from the Ministry of Economy and from the Regulator, were fully accomplished, if we take temperature effects into account. This fact is illustrated in figure 12, which shows the reduction in electricity consumption which would be needed to eliminate inefficiency in 2008, in comparison with our estimates for 2012. According to the efficiency level given by our model for 2008, electricity consumption in 2008 should have been lower than the actual value by 269 GWh, for the efficiency frontier to be attained (this value is illustrated in the first column of the graph). If we take into account the fact that the mild temperature conditions led to a reduction of 205 GWh in consumption, for normal weather conditions consumption should have been reduced by 473 GWh. Applying the same analysis to our estimate for consumption in 2012, the corresponding reduction is only 321 GWh. Hence, we have an increase in efficiency of 152 GWh, given by the difference between the targets for the efficiency frontiers in the two years. These predicted efficiency changes are aligned closely with the official targets for energy efficiency savings (156 GWh).

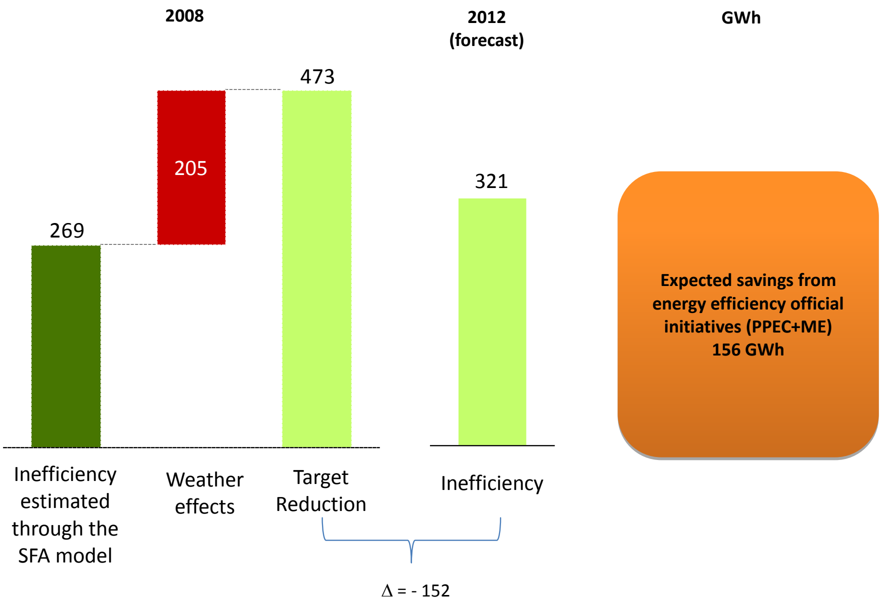


Figure 12: Estimated Targets for electricity savings derived from the efficiency model vs expected savings from official initiatives

13

Conclusions

In this paper we have outlined a new procedure for developing useful tools for modelling energy efficiency. These tools were successfully applied to electricity consumption in the Portuguese residential sector.

Through the application of an econometric model to a set of data collected from a survey launched to a sample of residential customers, we are able to identify priority regions and consumer bands to reduce inefficiency in electricity consumption. Hence, this approach may lead to the implementation of electricity saving measures in a more cost effective way.

Finally, through the application of the same method to a time-series data set, we related this efficiency measurement to policy developments in Portugal, concluding that the expected electricity savings from the efficiency measures introduced by the Government (essentially distribution of efficient light bulbs) and enhanced by the Regulator, through successive plans to promote efficiency in the use of electricity (PPEC – Planos de Promoção de Eficiência no Consumo), were fully realized. The corresponding savings, which amount to 150 GWh, represent 1.2% of household electricity consumption in 2012.

References

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[3] Weyman-Jones,_Thomas, Boucinha, Júlia and Inacio, Catarina (2012), Electric Energy Efficiency Trend in Portuguese Households, 4th Workshop on Efficiency and Productivity Analysis, Porto

[4] Coelli, Tim and Arne Henningsen (2012), Frontier, contributed package for R, R Development Core Team (2012), *R: A language and environment for statistical computing*, R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

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Lessons from a large scale energy consumption study in UK households

Chris Evans
Consumer Research Associates Ltd UK

ABSTRACT

Most authorities need to establish the types of data that can only be produced from household studies but are put off from commissioning them due to their anticipated cost and complexity. This paper demystifies these complexities and demonstrates a successful management structure that can be confidently adopted by any authority planning to commission such studies in future.

A study monitoring some consumer behaviour and the electricity consumption of all the domestic appliances in 250 households was completed in England in 2012. The results of the initial analyses and, uniquely, the entire 8Gb database have already been made publically available. Although this presentation will pick some headlines from the findings, its main theme is to identify the key features of the design and management processes that enabled this huge and complex research programme to be completed as specified, on time and on budget.

INTRODUCTION

There have been many small scale studies of energy consumption in households but few have been attempted on a national basis. Whilst the 250 households study reported here may seem large by comparison it is still small when compared to the 26million total of households in the UK.
(Note that the households monitored in this Study were all in England.)

The Study was commissioned by the authorities responsible for energy consumption and climate change policy in the UK. It was focussed on the consumption of electricity as additionally monitoring the consumption of gas and water would have more than doubled the cost of the planned programme.

There were two main needs that the study had to satisfy; one was identify what electrical products made the main contributions to consumption during the peak energy demand periods which, for the UK, occur during the coldest days of the winter. The other was to more reliably establish the average consumption for each of the major energy consuming products in domestic households. This data was needed for consumption projection modelling which, in the absence of any better data, would otherwise need to be based on assumptions about consumption patterns or on consumption data established in trials comprising just a few households. And, since the data from this study typically showed variations between the lowest and highest consuming households of some 500% for many of the different product types, it is clear that small scale household trials can yield very unreliable data due to the huge variation of household size, affluence and living patterns.

The purpose of this paper is not to discuss or share some of the findings of the study, remarkable though they were. Links to the reports of the findings are given at the end of this document. The purpose is to provide details of how this study was managed, what skills were needed to deliver it and what lessons were learnt that can be passed onto those undertaking their own large scale trials in the future.

THE ESSENTIALS

BUDGET
Undertaking a study to provide robust findings of national significance is likely to be a substantial undertaking. This study had a budget of €1million and an earlier, larger (400 households) study in Sweden is believed to have cost substantially more.

This UK Study was completed with an underspend of 5%.

TEAM MAKE-UP
The following roles each played an essential part in the delivery of the Study. All, except those making up the Governing Body, were contractors.

GOVERNING BODY
The Governing Body comprised of representatives of the commissioning Government departments. They initially drew up the specification of the Study and, following a competitive tendering exercise, appointed a consortium of contractors. All the bidders for the contract were consortia, this being a recognition that the variety of skills and experience required to deliver this Study do not normally exist within a single company.

The specification required the successful contractor to be responsible for all features of delivery i.e. the Government staff who commissioned the study would be left free to concentrate on its overall stewardship and so not be responsible for ensuring that specific parts of the programme were being delivered. All day-to-day management, all organisation, all problem solving etc. occurring within the Study being the responsibility of the contractors.

Once commissioned, the role of the Governing Body was to act as a Steering Group which met with the Managing Contractor (described below) every 3-4 months in order to monitor progress and to provide advice as needed. Over time, the Steering Group grew with additional members joining from the Government Departments that originally commissioned the Study. The diversity of steering group members represented a wide range of policy interests and this ensured the Study delivered data that could be used by several Government departments.

MANAGING CONTRACTOR
This Study required the delivery of a variety of technical solutions e.g. market research, installation of measuring equipment, data analysis etc. Put simply, it was the managing contractor’s job to ensure the smooth and successful integration of all these technical activities. The importance of this role should not be underestimated. There is a myriad of things that can (and do) go wrong in a study of this size and complexity. So there is a continuous need to develop and implement contingency plans and have problem solving expertise to hand. Importantly, the Managing Contractor for the Study was not responsible for providing any of the technical solutions, so was able to focus entirely on the overall management of the study without being distracted by the responsibilities of having to deliver one of the technical solutions too.

The Managing contractor thus developed and then monitored progress on the complex timing and activity plans to ensure each of the 250 households was recruited, interviewed, had instrumentation installed and later removed, maintained their activity diaries etc. This process worked very efficiently as the Managing Contractor assigned one person to manage the whole project. This ensured good project continuity but it did place that individual under considerable pressure at times.

This Study was completed on time.

TECHNICAL TEAM MEMBER (1) – MARKET RESEARCHER
It was known that locating suitable households was a task that organisers of studies often underestimate. In the case of this Study, the demographic profile of the householder sample needed to be a good match to the overall population in England in terms of:

- *Social grade* using a classification system enabling a household and all of its members to be classified according to the occupation of the Chief Income Earner
- *Number of people living in a household*
- *Life-stage*
- *Working status*
- *Property age*
- *Geographical region*

Thus a challenging task best undertaken by a professional market research company that already has this type of statistical data available and who has the recruiting capacity to locate not just 250 suitable households but also enough additional ones to act as a reserve in case some households drop out after volunteering. In the case of this Study, the drop-out rate was close to 30% - a strong indication of how challenging this aspect of the Study was.

Employing the skills of a professional market research company meant that attitudinal interviews could be undertaken at each household in the study. And, whilst there, the interviewer was able to conduct an initial audit survey to establish what electrical appliances were available for use in each household.

The interview ensured that data about social grade, household size, etc. was collected. The attitudinal survey covered pro-environmental behaviours segmentation, views towards climate change and energy saving. The appliance audit revealed that the average household had 41 appliances; the minimum found was 15, the maximum 85.

TECHNICAL TEAM MEMBER (2) – MEASURING INSTRUMENTATION SUPPLIER
The supplier (contractor) for the Study provided all the measuring instrumentation, data capture processes and data analysis. Having a single contractor to provide all the instrumentation, data capture and storage was attractive because it meant just one entity was responsible for a key part of the process which involved the interplay of several technologies. In the case of this Study, that contractor was also responsible for data analysis. This brought certain benefits but also some drawbacks – these elements are discussed in a later section of this paper.

One of the choices that needed to be made at the time of commissioning the Study was what measurement technologies were to be employed. Each of the consortia that tendered for the Study were required to make their own proposals and most chose to submit just one option rather than a choice. The options submitted varied. There were 3 main variations:

- Serial wattmeters for plug loads, combined with clamp-on meters used for individual circuits at the consumer unit – all measuring devices having some form of integrated data storage. The data being manually downloaded by a technician when visiting that household.
- Serial wattmeters for plug loads, combined with clamp-on meters used for individual circuits at the consumer unit – all measuring devices having some form of integrated data storage. The data being automatically downloaded and transmitted using ZigBee type technology.
- Plug load data capture using Radio-Frequency Identification (RFID) technology. The data being automatically downloaded and transmitted utilising the household's Wi-Fi router.

The choice made for the Study was to employ serial wattmeters for plug loads, combined with clamp-on meters used for individual circuits at the consumer unit with data being manually downloaded by a technician when visiting that household. The reason for making this choice was that it was based on well-proven technology of known reliability. The newer, higher technology options, though attractive as some were physically less intrusive for householders, did not have such a well-established reputation for reliability. Although remote monitoring meant that data streams could be checked in real time, the cost of dispatching a technician to make the necessary repairs could become very high.

One other important choice about the instrumentation was whether to purchase it or rent it. Rental was much less costly than purchase but it meant that the client departments would not have the instrumentation available for further studies once this Study had been completed. In this case, the equipment was rented.

Details of the instrumentation used for the Study are provided in the literature referenced at the end of this paper.

TECHNICAL TEAM MEMBER (3) – MEASURING INSTRUMENTATION FITTER
All households needed to be visited by a technician to fit the measuring instrumentation and again sometime later to remove it. During their return visit, these technicians also downloaded the captured data onto laptop computers for subsequent onward transmission for storage in the database and eventual analysis.

For the tasks they had to do, the technicians needed two key attributes. One was that they needed to be qualified electricians as minor dismantling of household electrical supplies was occasionally necessary in order to fit the measuring devices. Clearly, any such task had to be undertaken in a completely safe manner and in accordance with wiring regulations, so only certified electricians were employed for this task. The other attribute was not a technical one, for it required inter-personal skills. These were necessary as the electricians were, apart for the market researcher who made the initial recruitment visit to each household, the only person to person contact that the householders had with those running the Study. These electricians were also going to spend as much as one day in the household fitting the instrumentation and, because this meant them visiting every room in the house, could be rather intrusive at a personal level. Therefore, it was particularly important that these electricians had very good ”client management” skills i.e. were very polite, prepared to spend time with the householder to explain what they were doing, worked very tidily and were even attentive to small considerations such as removing their shoes when entering people’s homes.

This consideration might seem unnecessary but these “ambassadors” received excellent feedback from householders and on a few occasions were able to identify pre-existing safety faults in household wiring systems that they were able draw to the attention of the householder.

Prior to commencing their role in the Study the electricians (two small teams of electricians covered the whole of England) were provided with substantial training by the instrument suppliers.

TECHNICAL TEAM MEMBER (4) – DATA ANALYSER
Studies like this generate a huge amount of data (220 million lines of data in this Study) and those who commission them may not understand this aspect well – so can find themselves being offered advice about the provisioning of databases and analytical solutions that they do not fully understand the implications of. Some of this impacted this Study. The solution offered by the measuring instrument supplier, which was for them to also store the data in their preferred data base solution complete with their in-house analytical tools, was very convenient and produced elegant outputs in accordance with the wishes of the Steering Group.

In the short term, this provided a very satisfactory solution – the solution only being limited by the Steering Group themselves as they were required to produce a list of requested analyses. But this solution can impose limitations in the longer term as other parties begin to ask for analyses for which no solution can be provided other than through the inflexible and added-cost route of needing to request and pay the data base custodian (the Measuring instrument Supplier) to provide the required analyses.

The solution that was developed for this Study was to migrate all of the data into a MySQL database. MySQL was chosen as it is widely used open source software, so available to all would-be users. Such databases provide storage facilities only so need some additional features to enable users to access the data in suitable formats for their intended use. The following were developed for this Study:

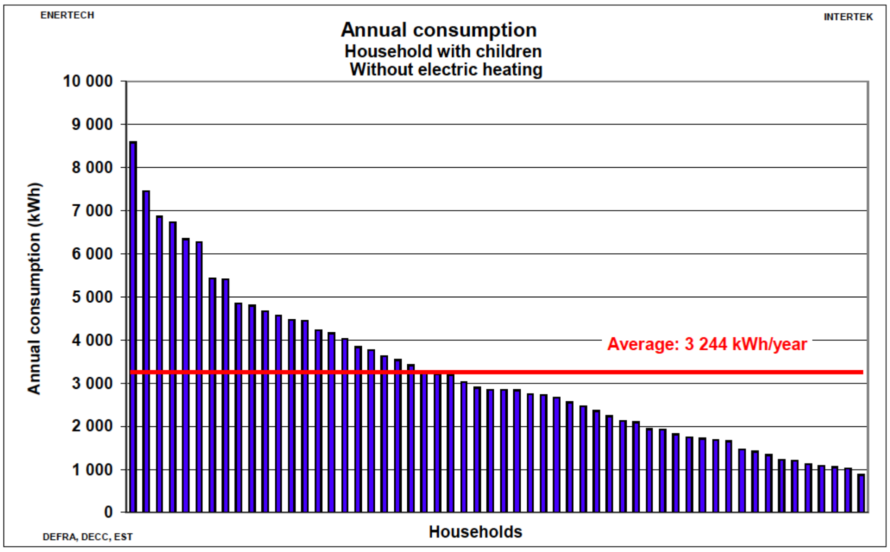
- WAMP database solution package with pre-defined queries (WAMP is a pre-packed set of programs that enable web based queries to be made of the MySQL database). This solution being designed to enable non-database base experts to run their own queries on the database.
- The MySQL database was given a Microsoft *Access* front end to allow users to design their own queries (users can use the core MySQL database and add their own front end). This solution being designed to suit those with some familiarity with databases, particularly the most common one MS *Access*,
- Or, for database experts, they would be able to export data files directly from the MySQL database.

SOME OTHER FACTORS

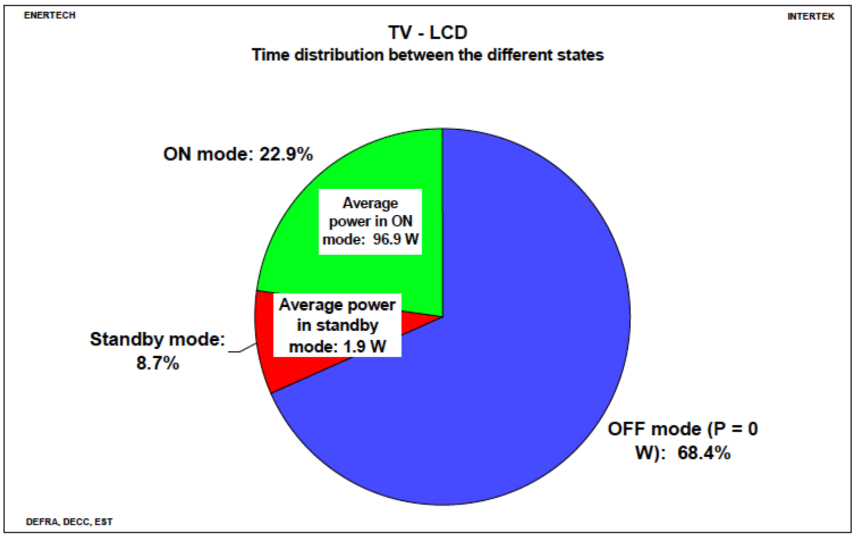
- All of the households in the Study were owner-occupied. It was not possible to recruit households from the social housing sector and rented sectors as the wiring needed to be modified to fit some of the measuring instruments and landlords were not expected to readily give permission for this.
- The most difficult household population to recruit was younger single occupiers. These were important to include as 29% of UK households are single person dwellings.
- Ownership of the intellectual property rights to the analytical tools required to analyse the database needs to be established at the outset.
- The detailed analyses that were required should be determined well in advance of completion of the study.
- Downloading of data during intensive (peak) periods could be intrusive for householders and should be done remotely where possible.
- Owning rather than renting the instrumentation may encourage the development of lower cost studies that can be used to refresh the data in future years.
- Only the data analyser could check the data as the project progressed and as much of this was done at the end it meant that problems with missing or corrupted date were not always spotted as early as they could have been.
- Appliances that are built into kitchen units in such a way that their power input plugs are inaccessible can be particularly difficult to monitor.
- Households that use portable electric heating to supplement a non-electrical main heating source need particularly close attention to ensure these extra heating sources are included in the monitoring programme.
- Studies such as this only provide a snapshot in time; so will eventually need to be repeated.

SOME EYE-CATCHING FINDINGS

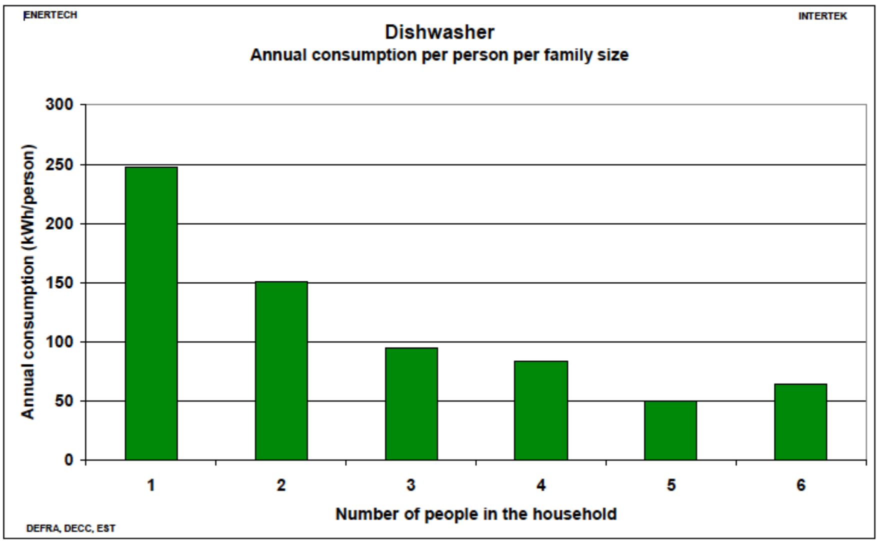
- The study found the total average annual electricity demand for all dwellings monitored in the survey (excluding electrically heated homes) to be >3200KWh.



- This average annual electricity consumption in the Study's households was 10% higher than the UK national average.
- Single person households were found to use as much, and sometimes more energy than typical families. This is particularly true of cooking and laundry activities.
- TV viewing is close to 6 hours in a typical day; the typical household having 2 TV sets…



- Although peak domestic electricity demand occurs at breakfast time and again in the evening, there remains a seemingly high baseline demand of 175-200 watts throughout the 01.00- 05.00 hours period.
- Excluding electric heating, the largest contributor to the average annual household demand is the combination of consumer electronics and ICT (20.5%), followed by cold appliances (16.2%) and lighting (15.4%). Cooking and wet appliances consume similar levels of energy at 13.8% and 13.6% respectively.
- UK households use much more energy to dry clothes (annual average 394 kWh), than to wash them (166 kWh) and they use more energy to wash dishes (294 kWh) than to wash clothes…



- Incandescent lamps accounted for the majority of lighting with close to 40% of all installed light bulbs. Halogens come next with 31%, demonstrating that CFL and LED technologies still have a huge market to penetrate and huge savings to potentially be made…

REFERENCES AND FURTHER READING

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Summary of UK report: *Powering the nation: household electricity-using habits revealed* http://www.energysavingtrust.org.uk/About-us/What-we-do/Recent-reports

Address to apply for a copy of the complete database: efficient.products@defra.gsi.gov.uk

List of Australian sub-studies into designing an enlarged (electricity, water and gas) household consumption study: http://www.energyrating.gov.au/resources/program-publications/?_wpnonce=2a79832528&_wp_http_referer=%2Fresources%2Fprogram-publications%2F&er_doc_query=REMP&er_doc_submitted_query=1&submit=Search&er_doc_year=&er_doc_category=&er_doc_subcategory=

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Acknowledgements

The Study that has formed the basis for the content of this paper was inspired by an earlier study of electricity in 400 households undertaken by the Swedish Energy Agency. The expert advice provided by Egil Öfverholm and Peter Bennich proved to be invaluable during the period when the specification for the UK study was being formulated.

Project ACHIEVE: promotion of practical and structural solutions that help Europeans to reduce fuel poverty

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Abstract

With rising energy prices, more and more households across Europe are facing fuel poverty. Although the problem is a complex one, some solutions are simple and cost-effective. The paper presents ACHIEVE (*ACtions in low income Households to Improve energy efficiency through Visits and Energy diagnosis)*, a pan-European action with practical and structural solutions that helps Europeans to reduce fuel poverty.

ACHIEVE works towards uniting the various definitions of fuel poverty across Europe and sharing approaches to better identify fuel poor households. It is known that these households are often not well reached by energy saving awareness campaigns oriented towards the general public, and thus do not seek the help they might need to improve their situation.

In this action, long-term unemployed people are mobilized and trained to carry out home visits to fuel poor households, where energy use is monitored while families are recommended tailor-made measures. The households are stimulated to reduce their energy and water use through energy saving devices provided free of charge and behavioural adjustments. The action's important social innovation is that it contributes to social reintegration, both by empowering households and by engaging long-term unemployed people to fight fuel poverty. Visits also provide an opportunity to identify complementary long term measures for improving the buildings' energy performance.

The action also looks for structural solutions, from building retrofit to financing mechanisms for abating fuel poverty at micro and macro levels. Some of the structural solutions for fuel poverty need to be formed at EU level and for this reason international collaboration in tackling fuel poverty is needed.

Short introduction to fuel poverty

Definition of fuel poverty

Defining fuel poverty has and still is causing numerous debates, but as this is not the topic of this paper, the issue is addressed only briefly. Brenda Boardman [1] explains the challenge in the following manner: 'Now that the fuel poverty is politically accepted as a real problem, there are some difficult definitional issues to consider. All of these are compounded by the circular argument: who is fuel poor depends on the definition, but the definition depends on who you want to focus on and this involves political judgement.'

At the EU level, there is no common definition of what constitutes a fuel poor household. However, one way of defining it, which is used in practice, is that a household, which has twice the median fuel expenditure as a proportion of income, is facing fuel poverty [2]. Another commonly used definition is that any household that would need to spend more than 10% of its annual income on having adequate energy services is in fuel poverty [3].

For the purpose of the project ACHIEVE, the following definition of a fuel poor household emerged: a fuel poor household is one that has a difficulty, or sometimes inability, to be able to afford its basic energy needs [4]. Households in fuel poverty have energy costs, which are excessive, compared to overall household income.

Causes of the problem

Fuel poverty is mainly caused by the convergence of the following inter-related factors [5]:

• low income, which is often linked to general poverty

• high energy prices, including the use of relatively expensive fuel sources

• poor energy efficiency of a home, e.g. through low levels of insulation and old or inefficient heating systems.

Heating is the first item that strains the global energy bill for a household (around 70% of the annual energy consumption). However, the running of appliances and the energy used for hot water consumption are also important: appliances account for a growing proportion of households' energy budgets (low income households tend to use older and more inefficient appliances), and water consumption is showing a general tendency to increase (amongst all categories of households) [6].

Scale of the problem

Even though the European Union is one of the richest areas in the world, many EU citizens have such limited resources that they cannot afford the basics. Between 50 million and 125 million people (about 10 – 25 %) in Europe are estimated to be fuel poor [7]. The span of fuel poverty estimations is so large mostly because – as explained above – in many countries there is no definition that constitutes fuel poverty and since there is no definition, there are no statistics [8]. However, most of the evidence shows that the problem is inevitably deemed to increase in the future, in line with rising energy prices [9]. The problem is particularly expressed in the eastern European member states, where the energy liberalization strategies, which had to be put in place to access the EU, led many households from a situation with subsidized energy prices into a situation with market based energy prices, which meant (and still means) a major rise in costs for them [10].

Health impacts of fuel poverty

Fuel poverty has considerable physical and mental impacts. Living in a cold home exacerbates circulatory and respiratory conditions and accounts for around 40% of excess winter deaths. Around one third of excess winter deaths are due to respiratory illness [11]. Older people are more likely to be vulnerable to cold weather, partly because they are more likely to have existing medical conditions. However, other vulnerable groups include young children and people with long-term illness. Home energy improvements have proved to decrease school sickness absences by 80% in children with asthma or recurrent respiratory infections [12]. People living in homes with bedroom temperatures at 21 °C are 50% less likely to suffer depression and anxiety than those with temperatures of 15 °C [13].

Project ACHIEVE in a nutshell [14]

Project ACHIEVE is an Intelligent Energy Europe [15] supported pan-European action with practical and structural solutions that help Europeans reduce unnecessary energy and water use. The action reaches to low income households that are most vulnerable to fuel poverty and works with them to reduce their consumption. It links dispersed local actors into an EU-wide concerted effort to reduce fuel poverty and develops common tools and methodologies for addressing energy poverty at the European level.

Starting point of ACHIEVE in the covered countries

Although in some countries (UK, France and Germany) activities, similar to ACHIEVE, already exist, the programme is upgrading the existing activities. In France, several local initiatives have been in place for more than 15 years to implement actions against energy poverty, most of them relying on the housing solidarity fund, which helps people who have difficulties to pay their energy bills. Only recently an action started at a national level, the so called Grenelle Plan for Buildings. ACHIEVE in France builds on those initiatives. In the UK, UK fuel Poverty Strategy, the Climate Change Act and the Energy Act are the bases for fuel poverty action. Some local authorities have established Affordable Warmth strategies and partnerships, however there are many areas where activity is very limited and support is needed. ACHIEVE works with those, while also building on the results of initiatives to improve the insulation, such as Cavity Wall and Loft Insulation. In Germany, more specifically in Frankfurt, initiative “Energiesparservice” (energy saving service) has been in place since 2005. Unemployed people are being qualified as “Service Consultants for Energy and Water Saving Techniques”. With the necessary measuring and testing gear, informational brochures and sample equipment, the consulting teams go to low-income households and document the current usage of electricity, water and heat with the help of a comparison chart. ACHIEVE benefits from sharing the experiences of this initiative and transferring them to the other partner countries.

In Slovenia and Bulgaria the initiatives for abating fuel poverty are practically non-existent. In Slovenia there is an existing financing scheme for refurbishment investments of low-income households, while in Bulgaria grants are available through the National Programme for Refurbishment of Dwelling Buildings. The direct state subsidy amounts to 20% of the basic package of measures necessary for refurbishment of the buildings. There are many questions opened about the criteria related to the ways of supporting low income households.

Aim and objectives of the action

The aim of ACHIEVE is to contribute to practical and structural solutions for reduction of fuel poverty in Europe. The strategic objectives of this action are the following:

• Improve health and well being for households facing fuel poverty,

• Link dispersed local actors into an EU wide concerted effort to reduce fuel poverty, through common understanding, communication and networking,

• Reduce social exclusion and marginalisation of households that suffer fuel poverty

• Develop a methodological and economical concept for addressing energy poverty at the European level

Activities of the project

Basing its approach on the best practices throughout Europe, ACHIEVE identifies households that are most vulnerable to fuel poverty and works with them to implement suitable steps to reduce unnecessary energy use and of course, costs.

Indeed, private households do often not take up or know the solutions they can mobilise to decrease their energy consumptions and bills. The information available often does not fit their specific situation. In addition, this target group lacks the financial resources to make energy efficiency investments in their homes A proper understanding of their situation, through a socio-technical diagnosis during a home visit, is the very first step to be able to help them further and orientate them towards existing solutions and support.

In ACHIEVE, long-term unemployed people, volunteers or students are mobilized and trained to develop a large-scale campaign of home visits to households who have hitherto not had access to help and support, and who are facing difficulties with paying their energy bills.

The service is based on home visits, with the main purpose to identify on a case-by-case basis the everyday actions that can have a real impact on their energy consumption. Visits focus on the following points:

• to understand vulnerable consumers' energy consumption, bills and habits, and to check their appliances with a set of reporting/analysing tools;

• to distribute and install a set of energy-efficient and water-saving devices (such as light bulbs, power strips, tap aerators…), which are free of charge for the households, and give advice to the households on how to implement further practical measures for saving energy;

• to analyse which longer term solutions can be introduced to improve the households' situation, by linking local actors into a concerted local action plan.

Fuel poverty and long-term unemployment are often linked with social marginalisation. ACHIEVE's important social innovation is that it contributes to social reintegration, both by empowering households to fight fuel poverty by improving understanding of their energy use, and by engaging people who have been unemployed long-term to raise awareness on fuel poverty.

A crucial programme activity is to trigger building improvement when thermal improvement works are needed: by better connecting tenants and landlords, informing, motivating and orientating them with easy to understand and tailored documents and methods. To do this, project partners cooperate closely with tenants, home owners, landlords, social services, consumer protection agencies and other relevant actors.

Expected results and impacts of the project

ACHIEVE runs from May 2011 until April 2014. It is expected that ACHIEVE will result in:
• changing energy using behaviour,
• introducing energy efficiency measures at the level of individual households,
• reducing overall energy consumption and thus reduce the risk of energy poverty in target households, energy savings and
• a reduction in CO_2 emissions in each household visited,
• developing competences and job opportunities for those energy advisors carrying out the visits, and thereby
• reintegrating them into the labour market,
• improving health and well being for households facing fuel poverty,

• linking dispersed local actors into a EU-wide concerted effort,
• reducing fuel poverty, through common understanding, communication and networking,
• reducing social exclusion and marginalisation of households that suffer from fuel poverty and
• developing a concept for addressing energy poverty at the European level.

2600 visits are planned to be implemented within the frame of the ACHIEVE in 2012 – 2014 (300 to 500 visits in each of the 6 target areas of the project). Each ACHIEVE visit targets the following reductions, depending on the countries and the saving devices offered:
• 400 to 500 kWh decrease / household /year
• 150 to 300 kg / CO2/ household / year
• 20 to 30 m^3 of water / household / year

These figures are based only on the calculation of the direct savings generated by the installation of energy and water saving devices at the households. They don't take into account the potential savings generated by the application, by the family, of the advice and tips given during the visits. To monitor the achievements of the project, evaluation will be a separate step in the process. Evaluation of the success will be done through interviews with the visited households.

The ACHIEVE concept is based on the idea of promoting climate-friendly behaviour, together with money savings considerations, - specifically for low-income households. Developing and replicating ACHIEVE methodology in Europe would definitely contribute to meet the 2020 EU target consisting in a 20% reduction in EU greenhouse gas emissions.

Target groups of the project

The key target group consists of households that have difficulties in affording basic energy needs. Through diagnostic visits and the installation of free energy saving devices they can save energy and money by better controlling their energy consumption. The visits show them where and how they can save energy and water and help them to decide what behavioural changes to introduce.

This implies working with any other local actor that might be able to identify the targeted households and be relevant to proposing longer-term and durable aid or solutions to the households, after the visit.

Other target groups are:

• *Local authorities* with access to information on how to reduce fuel poverty. They can support housing schemes and housing renovations that secure sustainable energy consumption and improve well-being of occupants. They can support the households through their technical or legal services.

• *Owners of buildings* in which fuel poverty situations are concentrated: by learning how to improve energy performance of the building they can improve the living conditions in their buildings and improve the value of their property.

• *Local actors* (such as local housing associations, tenants' associations, health, energy or social actors, for whom addressing poverty challenges are at the core of their mission) can both benefit from and take part in implementing the project through networking and shared competences.

• *People* who have the right basic skills to be trained to give energy advice to low income households, such as volunteers, people who are long-term unemployed or students that wish to gain work experience.

Partners of the action

ACHIEVE project partners are
• **CLER** - Réseau pour la transition énergétique (Coordinator; France)
• **CARITAS** - Energiesparservice Caritasverband Frankfurt e.V. (Germany)
• **EAP** - Energy Agency of Plovdiv (Bulgaria)

• **FOCUS -** društvo za sonaraven razvoj (Slovenia)
• **GERES** - Groupe Energies Renouvelables, Environnement et Solidarités (France)
• **IDEMU** - Institut de l'Ecologie en Milieu Urbain (France)
• **Severn Wye** - Severn Wye Energy Agency (UK)

Local circumstances in countries, covered by the action

This chapter describes the situation in each of the countries where ACHIEVE is trying to make an impact. This is to describe the backdrop against which the activities of the project are set [16].

France

In France, it is assumed that between 4 and 5 million households face fuel poverty. Either because they spend more than 10% of their income on energy costs, or because they impose self- limitations on their energy consumption and suffer from cold homes. Despite a national plan and funding scheme starting in 2010, (aiming to help 300,000 tenants with low-incomes to improve the energy performances of their home by 2017) visits remain the first step for any action, whether it is on occupant behaviour or actual energy efficiency upgrades to the building itself. If visits are not clearly organised, they are not implemented at all. The success of the national plan depends on the local actors and authorities to find a way to identify the concerned households in their territory, and to organise and finance these mass visits. Several local initiatives are being implemented in France to fight energy poverty, similar to ACHIEVE activities. Within the framework of ACHIEVE, the French partners have set up a national task force to build a range of structures for carrying out these type of projects that offer visits. Partners include local authorities, enterprises that work on the integration of immigrants, and non-profit organizations. This task force aims to exchange and share each structure's experience, and to push forward the need and opportunities for public authorities to participate in such type of actions. The final aim of the task force meets the ACHIEVE goal: to develop an economical and organisational pattern for mass visits.

Bulgaria

The term fuel poverty has no concrete definition in Bulgarian legislation. For the purposes of the project, we define a fuel poor household as one that applies for social aid to cover heating costs during the winter. The Social Ministry in Bulgaria grants aid for heating during winter to selected households. The target group of ACHIEVE consists of/includes households applying for this kind of aid. An important target group is households that use coal for heating. As part of the project Energy Agency Plovdiv will co-operate with the Ministry of Environment and Water and the Ministry of Labour and Social Policy to propose and implement changes in the current legislation, so that the use of inefficient and polluting coal in heating is discontinued and, instead, use of modern sources of biomass is encouraged.

Slovenia

Due to growing prices of energy, fuel poverty is becoming an alarming issue in Slovenia. Approximately one third of the households in Slovenia suffer fuel poverty (as specified by the UK definition). However, energy prices are not the only contributing factor. The poor condition of buildings is also relevant. 44.5% of low income families and 28% of families with higher incomes live in humid and poorly maintained buildings (leaking roof, humid foundations, floor or walls, shattered windows). This means that in Slovenia fuel poverty could be widespread also in households that are not strictly poor, as poorly maintained buildings cause high energy consumption and hence high costs to the residents. In the municipality of Ljubljana, where the Slovene ACHIEVE activities take place, more than half of the buildings date between 1945 and 1990, which characterizes the flats as energy inefficient. Yet, there are many unresolved questions as how to identify the households in need of support.

Germany

In Germany, there is neither an official definition for fuel poverty nor is there statistical data about people who live in fuel poverty. The German consumer protection association estimates that more than 800,000 households (2%) are cut off from their power supply each year because they are not able to pay their bills. The energy prices in Germany have gone up continuously over the past few years. After liberalisation of the electricity market in 1998, the average price for electricity has risen from 15 cents to 24 cents per kWh in 2011. At the same time, households lack control of their energy usage because they only get a bill once a year, based on their yearly consumption. This leads to significant problems for low-income households whenever they have to manage additional payments at the end of the year. For people with low income, e.g. people who receive social welfare or long-term unemployment benefits, the costs for heating, water and water heating are paid by the municipality. Thus the main problem is how to pay for the electricity consumption for cooking, washing and cooling. Only 5 % of the German households use electricity also for heating.

United Kingdom

Project ACHIEVE comes at a time when an unfavourable economic climate and rising energy prices have impacted those groups who both traditionally and recently are considered to be at risk of energy poverty. In 2009, the number of fuel poor households in the UK was estimated at around 5.5 million. In the UK, project ACHIEVE is based in the county of Wiltshire, in the western region of the county which statistically has a higher propensity towards energy poverty. Wiltshire has been working towards creating training and employment opportunities for its residents; a policy designed to mitigate the impact of the economic recession. ACHIEVE will work to address the training needs of residents in line with the ‘Green Deal’ a flagship energy efficiency policy for the domestic sector based on a ‘Pay as you save’ model. The government expects around 250,000 new jobs to be created as a result of this policy. Project ACHIEVE hopes to help advisors on the road to employment within this sector and to develop a local, skilled workforce.

Transferring experiences and know-how

ACHIEVE covers some countries where advising households on how to abate fuel poverty is already ongoing (Germany, UK and France) and others where fuel poverty is hardly tackled at all (Slovenia and Bulgaria). For this reason the first step of the programme was to present to partners from all the participating countries how energy efficiency measures and equipment are being introduced in German households.

Caritas Frankfurt has been running a programme for empowering households to act on fuel poverty since 2005. The programme, called Energiesparservice, was developed jointly by Rhein-Main Energy Supplier and the Department of Social Services of the city of Frankfurt am Main, JobCenter Frankfurt am Main and Caritas Association Frankfurt. The programme started with 12 advisors who were long-term unemployed and has now developed into a national initiative called “Stromspar-Check” in over 100 cities and communities in Germany [17].

The programme empowers households by two visits of energy efficiency advisors. During the first visit, the advisors check the household’s equipment and energy bills. Based on the check, calculations are made on where to save energy most efficiently. A set of recommendations is made and during the second visit, the experts install easy-to-use energy saving devices like efficient bulbs, tap aerators or power strips. They also provide advice on changes in behaviour to further save energy and water. Practical experience from the programme so far shows that annual savings for households can run up to 140 EUR yearly and more than 1100 EUR in long-term-savings [18].

As this programme has been successfully running since 2005, it was selected to be the starting point of ACHIEVE. The project partners visited Caritas in Frankfurt in May 2011 to see how the visits are implemented in practice. Apart from the visit, the partners also translated Caritas’ “Guidelines

Introducing Advisory Services on How to Save Energy in Low-income Households" [19], which describe the concept of service of Caritas Frankfurt, called Cariteam Energy Saving Service, and the procedure of introducing and implementing the project step by step. To provide material for trainings of energy advisors, Caritas also developed a "Curriculum for Specialized Training on Saving Energy and Water" [20]. The curriculum covers topics such as general introduction to energy, detecting fuel poverty situations, showing a concept of thermal comfort and heat loss, procedure and data documentation, evaluation and installation of devices or communication training. For each chapter, a corresponding module has been developed – contents, tips about the method of presentation (exercises, group work, role playing, homework, etc.), and time frame. This curriculum was taken as a general basis for defining, designing and developing training modules and exercises for all ACHIEVE partners.

Equipped with the materials, the partners implemented trainings for energy advisors. Each partner decided to use a different approach to identifying and training energy advisors (see Table 1).

Table 1: Approaches to identifying and training energy advisors in project Achieve

Partner	Used approaches
IDEMU	4 people in an integration programme have been recruited for 6 months and trained by IDEMU. The recruitment was done by IDEMU, in cooperation with key recruitment offices. An information event was organized in January 2012 to present the project and the mission to the applicants, followed by individual interviews.
GERES	GERES works with people in an integration programme. GERES decided to work with EVOLIO, an NGO implementing integration programmes. The recruitment was organized by EVOLIO in close cooperation with centre for unemployed and a youth organization.
SWEA	Advisors are people who have been long term unemployed. Advisors were recruited through Job Centre Plus. Their training will form part of a national initiative to remove barriers to work- the Sector Based Work Academy
CARITAS	Caritas works with long-term unemployed people, people in an integration programme and volunteers. People for the integration programme are pre-selected by the job centre. Volunteers are recruited through PR activities.
FOCUS	Focus works mainly with unemployed people (some long-term unemployed) and some recently graduated young people, who seek experience. The recruitment was done through promotion (leaflet, mailing lists, news and social networks) and presentation at the Office for Employment. 12 advisors were selected and trained.
EAP	EAP works with students from professional schools. Agreements with two professional schools (for household technology and for electric technology) have been signed. The training served as an addition to the students' curriculum. The visits that they implement give a chance to put their knowledge and skills into practice.

Source: First project report

Detecting fuel poor households

Fuel poverty is not a term that households will apply spontaneously to themselves, hence they often need to be detected. They can be identified through a number of relevant indicators including [21]:

• The inability to pay energy bills,
• Cold damp living conditions,
• Disconnection from energy supply,
• Self-disconnection (in some countries),
• Debts owed to the energy supplier,

• Health impacts associated with poor living conditions,
• Homes with low energy performance

Thus, the first challenge for ACHIEVE when setting up local action plans to tackle fuel poverty was to identify those households that are facing problems in affording their basic energy needs. This challenge was tackled by exchanging experience between partners/countries: - looking to identify fuel poor households, - implementing site-tailored discussions and interviews with key actors and affected households - elaborating reports on the findings [22]. Based on the analyses and consultations, the partners decided on their target group – households that were identified to be the most prone to fuel poverty, as described in Table 2.

Table 2: Parameters for identifying fuel poor households

Location	**Used parameters for identifying fuel poor households**
Frankfurt, Germany	Results of the evaluation of the programme Energiesparservice, which offers visits to fuel poor households, show that 32 % of the households have a migration background, 66 % are unemployed and 20 % receive social welfare because of other problems. 35 % are single households, 18 % are single parent families and in 26 % of the households there are four or more members. The main problem for these households was their inability to pay their electricity costs. In Germany, there is neither an official definition for fuel poverty nor is there statistical data. There are only some indicators for fuel poverty: very low income or social benefit, problems to pay the bill, cutting off from power supply. More than 8 million people (thus about 10 %) in Germany use social support. The consumer protection association estimates that each year more than 800,000 households (that equals 2 %) are cut off from their power supply because they are not able to pay their bills.
Plaine Commune, France	Given the problems of private housing and socio-economic characteristics of the population, Plaine Commune appears to be particularly vulnerable to fuel poverty. The area is very exposed to poverty, with 30% of people living under the poverty threshold, compared to 13.6 % at a national level. In 2009, 21,546 people were in receipt of income benefits, and 4,649 households received financial aid to pay energy bills. This aid is proposed in the case of severe fuel debt and with the intervention of social services. There is no specific data or statistics to estimate the number of people in situation of fuel poverty. The tenants from private housing seem to be particularly vulnerable to fuel poverty in Plaine Commune: 78% of them live in a building built before 1975 (71,5% for owners, 69% for tenants of social housing). 53% of the buildings are heated by electricity, which is the most expensive type of energy in France (23 % for owners, 18% for tenants of social housing).
Marseille, France	Households in this region are extremely poor: between 50 and 70% of the population live below the poverty line. 20% of the population is unemployed and 30 % have part time jobs. The majority of the households benefit from social welfare (70% receive financial support for housing, 30% support for health security). Around 60% of the households benefiting from social welfare are families with children, including around 16% of families with more than 2 children and 25% of single parent families. In general, the thermal performance of the buildings' stock is very low in line with the age of the buildings' stock. Hence a significant part of the population is at high risk of energy poverty.

Ljubljana, Slovenia	The unemployment rate is currently slightly under national average – 9,9 % compared to the national 11,5 %. More than half of the buildings date between 1945 and 1990; this characterizes the housing stock as an energy inefficient one. Structure of social welfare does not allow bills to be paid by the welfare organization; they are paid by the individual regardless of circumstances. 11 % out of 813,531 households nationally are low income households. Thus they live below the poverty threshold. But if we take the numbers for fuel poverty, the percentage rises to 30 % of persons in Slovenia (British definition of fuel poverty). Target group are households on social benefit or receiving less than 300 EUR/month/person (as those often fall just short out of the social benefit system).
Plovdiv, Bulgaria	In 2010, 9,056 households applied for the Winter Supplement Programme and 7,138 of them received funding. The Winter Supplement Programme provides partial funding for households' heating bills. To receive funding from the programme a household has to meet certain criteria such as: income level, dwelling size, health or other conditions, etc. In the city of Plovdiv approximately 36% use wood or coal for heating, 23% use electric energy, 21% use district heating, and 20% of the homes are unheated. About 60% of the buildings are 30 years old or older, many of them constructed from prefabricated panels and are categorized as highly energy inefficient. The analysis showed that the target group are people who apply for funding through the Winter Supplement Programme and especially of people who are using inefficient ways of heating (for example, low-quality coal and electricity).
County of Wiltshire, UK	In 2010, 8.8% of Wiltshire (39,100 people) was classified as low income. Social welfare benefits include paying for rent, council tax relief, child care vouchers and winter fuel payments. In Wiltshire, 26,650 were claiming benefits in May 2011, 9.3% of the working age group (15-64). In 2011, 1% of Wiltshire's population (99,510) were of retirement age and older. This group is set to be the fastest growing group in all population. The Building Research Establishment estimates that around 12% - or 19,777 – of households in Wiltshire are in fuel poverty. The target group should, besides active recipients of benefits, also include households earning £15,000 per year or less. The elderly is also a growing target group.

Source: Achieve. *Report on the specific areas targeted in ACHIEVE.* 2012. http://www.achieve-project.eu/index.php?option=com_phocadownload&view=category&download=49%3Adescription-of-the-areas-targeted-in-achieve-d23aeu-version&id=1%3Aeu-targetareas&Itemid=6&lang=eeu

Reaching out to households

An important element of the ACHIEVE approach was developing a methodology for accessing the target households. The decision on methodology was based on learning from various projects, which showed that: there is a need for being proactive in approaching households, community engagement (neighbourhood events for example) demonstrates success, opportunities for co-promotion with partner organisations working with the target group should be sought after, promotion of the service through local media is useful and advisors could explore the possibility of promoting the scheme in ways that the community responds to: for example, by activities such as door-to-door canvassing to reach hard to reach households [23].

Bearing this in mind, the partners developed a variety of communication campaign approaches and tools to reach target households. The information about the project was given to target households by a variety of local actors, such as welfare associations / non-profit associations, municipalities and local authorities, utility providers, presentations in newspapers, unions of low-income, disadvantaged people, employment offices, social housing providers, social landlords, and community foundations

[24]. Communicating with agencies who work with families is important to gain access to the households. Additionally, German and UK projects have found that in order to empower households to make real lasting changes to the way that they use energy other agencies who interact with clients need also to be informed about the project: its aims and possibly key messages can help to keep households motivated [25].

There are many projects that have aimed to provide energy advice to households with the overarching aim of reducing household energy expenditures. A running theme of much of the partners' research demonstrated that web-based support tools can be very effective in communicating energy advice messages both to households and also to stakeholders [26]. Another approach, which turned out to be successful, is joining households together in a neighbourhood to help them to work together to save energy as a community competing against other such communities [27]. Also children may be a key agent of change as they are well versed in current discourses around environmental issues [28]. This learning could be incorporated into tailored energy advice reports to help motivate behaviour change in the whole household. Other examples put forward by partners suggest that a competition element with the prospect of prizes can help to stimulate households. Again, this may be an area where partners can explore the possibility of directing clients to such initiatives on a case-by-case basis [29].

The key messages communicated to the target households were shaped based on the inputs of focus groups and interviews, which showed that the emphasis should be on reduction of costs (not environmental matters), on the fact that it is a free offer (no long term engagement), free-of-charge devices, neutrality of the advisors and the structures managing them [30].

Implementation of the visits in households

Identifying the devices to be given to households

In order to manage energy and water consumption well, one has to have the appropriate knowledge as well as access to various devices in order to be able to reduce energy and water consumption. Due to their general financial situation, households facing fuel poverty are often the same as those who have less opportunity to purchase energy and water saving devices [31], or even simply have less or no information about their existence. The devices can be efficient light bulbs, appliances, and consumer electronics, thermometers and thermostats, weather stripping for windows and doors, transparent insulation foil for simple-glazing, tap aerators, dual-flow flush mechanisms, and even shower timers. One way to alleviate fuel poverty is to make these devices more accessible for households at risk, either by providing them, or by installing them. The impact of these devices can be easily measured in kWh or litres of water, which are easy to convert into monetary units [32].

The first step in deciding which devices to offer free of charge to households was to gather a list of possible energy and water saving devices and estimate their savings potentials, costs and ease of installation. The scope of devices was developed jointly by the partners, with the assistance of CARITAS experience. This resulted in a list of 26 devices to be potentially used [33]. It showed the devices that appear to offer the highest savings are those related to space and water heating. However, some appliances in this field (often those with the highest savings) will require more skill and time to install. The partners made their device packages and decisions based on the following aspects [34]:

• Time and skill needed to install the devices (e.g. drought proofing is really efficient, but it can take a lot of time and skill),

• Devices must fit to the household's situation: some devices may be systematically distributed (thermometers, CFLs, etc.), but some devices will be installed only when relevant (e.g. transparent thermo cover insulation foil for windows - only where single glazing is currently available),

• Availability and costs of each of the devices on the respective national markets (linked to the willingness of transferability and reproducibility of the project activities),

• Targets on energy savings and CO_2 reductions,

• Quality of the devices - people need to accept the material (user-friendly) and to be able to count on its efficiency for a long time (quality).

Advising the households

On the basis of the information and documents CARITAS brought to the consortium through its experience in Energiesparservice, the implementation of the household visits was prepared. The first step was organizing an Excel tool to gather and analyze data, and define the devices/tips to be given in priority. Next step was to organize the corresponding data collection sheets to report information about energy and water consumptions/habits of the households during the visits. Each partner adapted the final tools to its country context (language, energy prices and emission factors, heating systems, currency, devices used, etc.) [35].

Another step was to define the format of the visits. Generally, the following approach is used [36]:

• Procedure before visits: getting in touch with the household (appointment and first contact);

• First visit: analysis of water and energy consumption and habits;

• Second visit: installation of the most relevant devices according to previous observations and calculations from the first visit, likely to generate the best savings for the households; delivery of report and tips for behaviour change;

• Third contact (minimum 6 months later): this contact is made over phone to help evaluate the effects of the visit (currently a questionnaire is being finished).

Experience showed that a minimum of 8 hours is necessary for each household visit: travel, presence in the households (1-2 hours x2 visits), analysis of data collected at the household, and evaluation of impacts [37]. The number of energy advisors to visit a household varies in the countries, depending on the feedback received from focus groups and interviews at the beginning of the project, as presented in Table 3.

Table 3: Number of energy advisors for visiting households in project ACHIEVE

Partner	Number of advisors
IDEMU	The 1st visit is made in teams of 2 advisors, and the 2nd one by a single advisor.
GERES	The visits are implemented by two advisors at the start of the project. Then, if the energy advisors feel more self-confident, they may do the visits alone.
SWEA	2 advisors per visit for at least the first 5 visits. After this advisors will be expected to operate alone.
CARITAS	Two advisors, one with more experience, one with less, are to visit the households
FOCUS	First 1 – 2 visits of each advisor are done in pair with a supervisor, the next visits are done by one advisor.
EAP	At the beginning there will be 2 advisors per visit, later this could be changed to 1 per visit, depending on the feedback.

Source: Achieve Project Report 1.

The energy and water saving devices that are installed have two main advantages:

• The devices support/initiate a general talk about how the households can improve their energy and water use in their everyday life, as well as the importance of taking care of their consumptions. As such, they generate more savings than just those linked to the installation of devices (i.e. savings linked to behavioural changes, which are, however, difficult to assess);

• The devices make it easier to get into the homes. The devices are seen like a present by the families. The visit is essential to be able to make a first analysis of the situation (socioeconomic situation of the household, technical situation of the dwelling), and then find structural solutions that will allow more ambitious and more sustainable savings, through an intervention on the building envelope itself or on the appliances (including heating systems). Often, poor households are not aware that financial or legal support exists and could help them retrofit their home or find the assistance they need.

Home visits implemented through ACHIEVE are a starting point to detect and understand critical situations. However, it is essential to find a way to link this type of local projects to national schemes or even European regulations, and make sure that the proper level of action is activated when and where necessary. All materials developed or adapted for the purpose of ACHIEVE home visits service (and notably training modules and saving calculation software) are dedicated to be utilized by any organization willing to implement such a service.

Developing structural solutions

As much as the household visits are designed to make a lasting impact, they cannot bridge the structural components of the fuel poverty problem: they cannot improve energy efficiency of the whole building, they cannot guarantee financial support needed for large investments in fuel poor households, they cannot reduce the general level of energy prices, nor increase the income level of the households. Hence one of the objectives of ACHIEVE is to coordinate key actors into a concerted effort for formulating long-term solutions and develop a network for implementing the long-term solutions. The project seeks to develop a concept for addressing energy poverty at the European level, through a set of tested and assessed structural solutions and a widely transferable set of tools, so as to launch similar experiences elsewhere [38].

One key field to look into is social housing, where the majority of fuel poor families live. Social housing is organized very differently in the targeted countries. Table 4 shows the most critical barriers to energy renovations in the owner groups. In most countries, either high initial costs or (more frequently) long payback times represent a critical barrier. The landlord-tenant dilemma is another fairly widespread barrier [39].

Table 4: The most critical barriers to improving energy efficiency of the social/professionally owned rental housing in several EU countries

		AT	BG	CZ	DE	FI	FR	IT	RO	ES
Genuine uncertaint	Conflicting information, mistrust of information		X	X				X		
	Heterogeneous outcomes								X	
	Uncertainty in measurement & verification		X	X				X		
Financial barriers	High initial costs		X				X	X	X	X
	Long payback time		X	X	X	X	X	X		X
	Access to/cost of capital		X				X	X	X	X
	Unwillingness to incur debt		X					X	X	X
	Occupant take-back		X		X			X		X
	Low/uncertain resale value of property				X			X		
Organi-zational problems	Landlord-tenant dilemma		X	X	X		X	X	X	X
	Collective decision problems		X	X				X		
	Short timeframe of decisions		X	X						
Lack of information & skills	Lack of customer attention and interest		X					X	X	
	Lack of customer knowledge		X	X				X		
	Lack of reliable advice								X	
Transaction costs	Lack of skilled service providers	X						X	X	
	High information search costs							X		
	Switching costs, concerns over disruption	X				X				
	Risks of failures in renovation	X	X				X			

Source: Entranze. *Working paper: Literature review of key stakeholders, users and investors.* 2012.

Large scale efficiency retrofit is one key element of developing structural solutions for addressing fuel poverty [40]. Financial aspects are the key barrier in triggering energy retrofits (long pay-back time, access to funds). Currently there is a lack of understanding of the process, the costs and results of energy renovations among owners. ACHIEVE will help to inform them by providing reference data bases. Information should encourage owners to undertake such works [41]. For landlords and owner occupiers, ACHIEVE will provide information tools about retrofitting measures (costs, interests) and local/national existing financial mechanisms. These tools will provide clear guidance on whom to contact to receive further information and advice.

Another structural solution is to provide pedagogical tools for the households visited, to link the often already existing but dispersed information (about energy or water consumption, prices, contracts, payments, social, economical, health, etc.) and to give insight into bills, selection of suppliers, availability of financial assistance, etc.

Evaluating the results [42]

To properly monitor the effects of the household visits and advising, an evaluation of the results will be conducted in the second half of 2013. The aim of the evaluation is to monitor the success of the project and the measures developed, to identify potential problems and find solutions to improve the programme. To do this, the evaluation is divided in 2 general parts:

• an impact evaluation to analyse qualitative and quantitative effects of the project, and

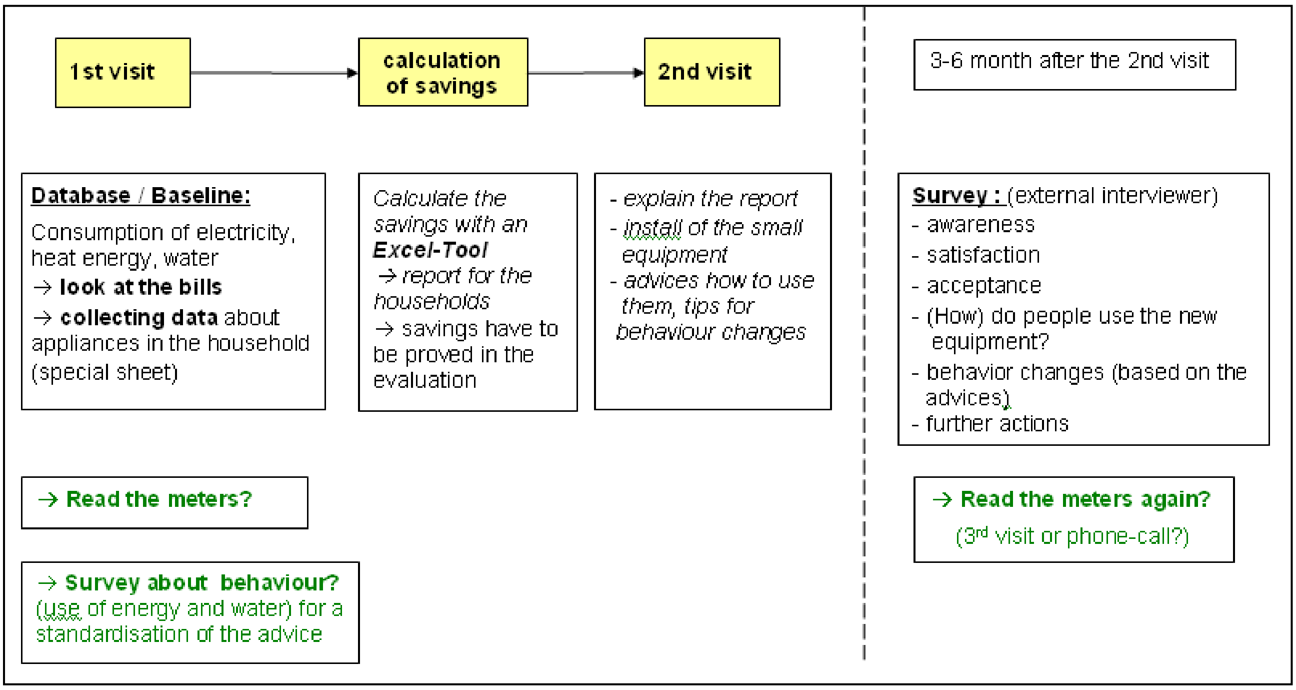
• a process evaluation to monitor the strategies set up within the project duration and the transferability of the methodologies and results.

The impact evaluation concerns the impacts that the actions undertaken by the partners have, for instance on environmental issues, social and security aspects, economic and comfort improvements for the households etc. This is based on quantified indicators and measurements defined in the initial evaluation plan, and précised in the interim evaluation report. Possible indicators include:
• The implementation of the advice (e.g. the number of mobilized local structures (associations, organisations etc.), management of financial support)
• The quality and quantity of the advice and savings (e.g. number of visits, the amount of savings, satisfaction of the households) and the cost-benefit-ratio
• The level of public awareness (e.g. total number of people reached by the dissemination of the project, participation to external /national / international events)
• The (re)integration of advisors into the labour market
• The number of landlords and owner-occupiers contacted and provided with targeted information on retrofitting measures.

The evaluation framework for the ACHIEVE-project is based on the experience of the evaluation of the Cariteam-Energiesparservice in Frankfurt 2009. It was adapted to the situation in the different countries. The concept of the development of structural solutions was added to the evaluation. The data-collection methodology is based around a mix of attitude and awareness surveys with specific target groups appropriate to the situation in each participating location.

The following chart shows the concept of the evaluation of the visits. At the first visit, a huge amount of data for the baseline-evaluation is collected. The savings from the installed devices and from the recommendations given start at the day of the second visit. Usually there is a period of 1-2 weeks between the visits. At least 6 months after the second visit, the conditions of the devices installed and the implementation of the recommendations are checked by a survey.

Table 5: Concept of the impact evaluation



Source: Achieve Interim Evaluation Report

Data collected at the first visit:
• Data about the actual consumption and cost of electricity, heat energy and water
• Data about the situation of the household (number of people, family situation, time spent at home every day, etc.)
• Data about the flat/house (size, age, energy standard, etc.), appliances used and water installations
• Data about the behaviour related to energy and water uses (e.g. way of ventilating the room, number and duration of showers, number of washes a week, etc.)

All the data is typed into an EXCEL-TOOL that was developed for the purpose of the project, based on the calculation tool of the Energiesparservice Frankfurt. The tool is used to calculate the savings generated by the visits and to collect data for the baseline-evaluation. That means that the baseline-evaluation is also a full part of the visit. The collection of these data can generally help to learn more about the situation of low-income households. On the other hand, it supports the visits and makes tailor-made advises and devices to the households possible. With the EXCEL-TOOL of ACHIEVE, a first calculation of the savings generated is possible. There are three different kinds of savings of energy and water:
• Savings based on the devices installed: These savings will be reached whenever people use the devices installed correctly (e.g. keep the CFL, always switch off the switchable power strip, etc.). In a report delivered to each visited household (during the second visit), people are given information about the potential amount of savings (in kWh, m³ and €) they can expect if they use the devices correctly.
• Possible savings by adapting behaviour: These savings will be reached if people follow the additional advices.
• Possible savings by own investment: These savings will be reached if people could buy new energy efficient appliances by own investment. They are given information about these possible savings (in kWh, m³ and €) in the report they are delivered.

A further possibility to check the savings is to read the meter several times. This is usually possible for electricity and/or water (if there is an individual meter for the flat). The consumption of heat energy, if it can be metered, is largely influenced by the weather and does not help to prove the savings. Special fields are foreseen in the EXCEL-TOOL to insert data read from the meter for electricity and water.

The questionnaire survey is the main part of the impact evaluation. It will be administered by telephone, and analyses the qualitative and quantitative effects of the advice. The survey will be organized by each partner / WP leader by themselves, by using the evaluation framework and a commonly agreed questionnaire. External support can be used by subcontracting.

For the evaluation, a minimum of 200 households visited in each local target area is necessary. Visits can be evaluated three month or later after the second visit at the earliest: households need some time to get experience in using the devices and to adapt their behaviour depending on the advise they receive (do they intend to make it an experimental behaviour or a new habitual behaviour, lasting in the long run?). They also need some time to buy new appliances by own investment if they wish to do so (like energy/water efficient fridges, washing machines etc.). Visits are planned not only during the heating period, to be able to reach the maximum clients within the 3 years of the project. The surveys should start in autumn 2013.

For the scientific validation of the analyses, a minimum of 100 feedbacks per target area or 50% of the visited households is necessary. People have to agree to be contacted again for the evaluation. It is thus necessary to ask whether a household would volunteer to participate in an interview at the first or second visit, and to complete a list of households that accepted to be contacted again for evaluation purpose. Individual survey results will be used to conduct an overall quantitative and qualitative assessment of the impacts of the project. It is recommended that an external interviewer asks the questions, to avoid socially desired answers. If the same people or even the same institution that the one offering the advice ask the questions, people could feel controlled.

The survey includes the following groups of questions:

• Acceptance and satisfaction: Awareness of the availability of the offer, reasons for using the advice, use of the energy saving products, satisfaction with the advice and the advisors

• Learning effects: Behaviour changes based on the advice, new appliances by own investment

• Multiplier Effects: Recommendation of the audits, public awareness of the project / of the issue

• Quantitative Effects: Savings of energy and water, CO_2, cost

• Further aspects: comfort, health, poverty etc.

• Socio-demographic items: sex, age, education, income, size of family, etc.

Some of these items, like family size, are already asked during the first visit. With the survey, it can be checked whether the number of persons has changed (could have an influence on the consumption of energy and water).

In addition to the questionnaire survey, some of the partners (precise) will organise face-to-face interviews with 10-20 households. The above described questionnaire will constitute the basis of the face-to-face interviews' process. This method will allow an extensive exploration of the level of satisfaction of the respondents regarding to the service proposed, giving them the opportunity to formulate recommendations. This way of data collection also minimizes non-response and maximizes the quality of the data collected.

The savings generated through the service have to be calculated by each partner. The savings are calculated for yearly savings and long-term savings (multiplying the yearly savings by the average lifetime of the devices and actions). A reduction is applied if the devices are not used correctly, especially for switchable power strips. People have to be asked questions about their behaviour changes in a very sensitive way, so that they do not feel controlled (e.g. "We would like to know if the devices fit for you or if we should improve the service. Here you can help us. How often could you switch out the power strip?"). There is another reduction of savings if devices are not used anymore. The experience of the Energiesparservice Frankfurt shows that some reasons can lead people to remove the devices they were given. For example, it can be people who did not like the colour of the light of the CFL, or dissatisfaction regarding the flow of water running from the tap, or malfunctioning of the water heater after installing the tap aerator, etc. It is helpful to ask for these reasons, to be able to improve the quality of the devices or the training of the energy advisors installing the devices. In addition to the savings that can be calculated in a precise way, some further savings from specific devices cannot be calculated exactly: it is savings generated thanks to the thermometer, thermo-hygrometer, key for the radiator, thermometer for the fridge or shower timer). On the other hand these devices are very important to support behaviour changes. Other effects, such as multiplier effects or further learning effects, cannot be counted in kWh at all. The savings will be taken to calculate a cost-benefit-ratio. For the transferability of the project it is necessary to know whether it runs cost-effectively. To calculate the cost-benefit-ratio, two groups of items should be compared: total costs of the project and total effects of the project.

ACHIEVEd so far

ACHIEVE's energy advisors have been visiting households in five European countries for more than a year now. The first results are therefore already visible (see Table 5). Please, bear in mind that the presented figures are not to be compared directly between countries as each of the covered countries applies a different approach to working with households (e.g. the devices given to households vary between countries hence also the savings are different). The presented figures are meant to show the first effects of the project.

So far, ACHIEVE partners have [43]:

• Designed and developed training content and modules for people recruited to perform the visits

• Designed and developed tools to be used by the advisors for the implementation of the visits (a guide on how to prepare and implement a visit, data collection sheets to collect data during a visit, a "software" to automatically calculate the savings generated by the energy and water saving devices distributed and installed...)

• Summarised, for organisations willing to develop such a service, the procedure and materials needed

• Designed materials to communicate on the service locally

• Reached a total of about 1000 households that received a visit,

• Trained 94 people to become advisors (among them, 57 students, and 37 volunteers/unemployed people).

Table 5: Estimated average savings from household visits of ACHIEVE

Country	No. of visited hh*	Avg. investment (€/hh)	Electricity savings (kWh/ hh/a)	Heating savings (kWh/ hh/a)	Water savings (m3/ hh/a)	Energy savings (%/ hh/a)	Water savings (%/hh /a)	CO2 savings (per site kg /a)	EUR savings/ hh/a
Bulgaria	203	30	793	389	5.4	9	8	126	91
France	138	44	260	815	31	8	26	243	142
Germany	270	60-70	296	693	14	N/A	N/A	433	173
Slovenia	59	31	283	412	13	7	11	248	92
UK	33	31	164	254	1.6	11	2.7	154	42

N/A The figure is not available at the moment.
* hh- household
Source: Data collected in visits to the households. Data is collected from the home metering and invoices of the households.

Key findings and lessons learned

As the project is still ongoing at the time of preparing this contribution, it is hard to draw final conclusions and lessons learned from the experience. However, some insights of what worked well and what mistakes can be avoided in the future are already available and presented in this chapter. The chapter is based on feedback provided by project partners during a project meeting [44] and interim report [45]

The first lessons from the project are oriented to the training modules for advisors. It was discovered that during training it is necessary to emphasize knowledge about social issues, so that the advisors are able to identify social problems (involve social workers in the training sessions so that advisors know how to identify social issues too, not only technical issues). It is also important to train communication requirements. The last important aspect is to clearly define the limits of the mission during the training in order to limit frustration among advisors and households (in practice it often happens that the household expects more than an advisor is able to give, as well as that advisors attempt to provide support for which they are not qualified to provide). In relation to this, it is important to better inform the advisors about possible solutions they can propose to households at the end of the visit (orientate them towards the proper structures).

In regard to selecting and training energy advisors several important findings came to light. The most important is that when recruiting energy advisors to be trained, a particular focus should be put on their social and communication skills: even if a large part of the work around the visits is technical (assessment and calculation of the main possible energy and water savings, advice given to households to reduce their consumptions…), the visits are also largely about “human” contact. Technical capacities can be strengthened, but this is not necessary the case with the ability to speak and listen to people. It is also suggested that visits are performed by two advisors, one of whom has an emphasis on technical skills, and the other has an emphasis on social skills or else one of whom is an experienced advisor and one a new advisor.

Another relevant finding is that people who wish to become energy advisors might have different expectations and the job does not necessarily suit them. To avoid disappointment when starting energy advising in practice it is suggested that the potential advisors do one visit before they get fully involved in the project, or have a movie to present the content of the mission – the aim is to clarify expectations before training. It is also advisable to work closely with the job agencies and employment centres in order to define the competences needed for energy advising.

When working with long-term unemployed people or volunteers, it is very likely that those who are trained to perform the visits will leave the programme when they find another job opportunity This means one has to plan regular new training sessions to train newcomers to the programme that replace the leaving advisors. Time dedicated to training activities should not be underestimated. This is the same for time dedicated to supervise/follow the advisors before they can be fully operational on their own (especially if the “turnover” of advisors is high). Training activities and general supervision of the visits are thus highly time consuming for project managers willing to implement a home visits service. It is a full time job for project managers. As a lot of support is needed to help advisors in the management of their own time, to plan the visits for them, to check the quality of the work and results that they are producing, it is advisable to receive some support from professional organizations when possible.

When dealing with households, it is of utmost importance to pay attention to their circumstances. Fuel poverty closely coincides with general poverty, which means that some of the households are very sensitive to their situation and are reserved in asking for support. It is advisable to have advising teams of one man and one woman, as it seems more acceptable for the households (in some cases it will even only be women who are accepted by the households). When working in areas where many immigrants are settled, it is preferable to work with advisors who are familiar with the languages of the immigrants.

Visits are a good occasion to get in touch with households who sometimes have not received any visits from “external” parties for a long time. As a consequence, the time needed for one visit can be much higher than expected, as people might have a lot to say to advisors (not necessarily strictly linked to the core purpose of the visit – this calls for social skills, as mentioned above). Also a lot of critical situations linked to unsanitary / inadequate housing or extreme poverty situations call for the need to organise, from the very beginning of the project, appropriate responses and procedures when such situations are needed. This means systematically linking with tenant/landlords mediation structures, sanitary services of the municipality, etc.

In regard to the local networks, the lessons learned are that creating and maintaining these networks (with social/health services mainly) is time consuming and it must be done regularly. One time contacts do not deliver long-term results. There can be barriers when working with social/health services. A possible solution could be sending a report on the results of visits (anonymous) to them to show and explain clearly the benefit of the visits.

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Community based social marketing and energy efficiency – an evaluation of engagement strategies and domestic retrofit policies.

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Abstract

It is widely acknowledged that efforts to reduce carbon emissions must consider strategies to improve the energy efficiency of existing building stock. A considerable number of policy options have been enacted to address barriers to energy efficiency improvements in the domestic sector. The Better Buildings Neighborhood Program in the United States has awarded competitive grants to state and local programs designed to transform the market for domestic retrofits. Therefore national level policy objectives are used to guide the creation of state and local programs and strategies that are specifically calibrated to their individual communities. These programs make use of similar but differing approaches to retrofit financing and end user engagement allowing for a comparative analysis amongst them. Many programs employ innovative methods of engagement with end users including community based social marketing strategies. This work examines case studies from two Better Buildings programs using a common methodology. This unique group of programs targeting similar objectives allows the opportunity to study the indicators for engagement mechanisms that most effectively translate policy theory into successful energy savings for the end user. In addition, it offers a discussion of community based social marketing in end user engagement strategies and policy design.

Introduction

This paper explores the issue of outreach in driving domestic energy efficiency retrofits. A number of barriers exist that limit the effectiveness of retrofit programs. This work explores some of these barriers and the past policy responses that have been used to address them. Furthermore, it argues that the community based social marketing (CBSM) methodology presents numerous advantages in reaching out to homeowners and driving participation in retrofit programs. Using two case studies from the Better Buildings Neighborhood Program in the United States, this work presents a methodology through which to approximate the quantitative impact of various outreach strategies as well as qualitatively explore the themes that deliver successful outreach for retrofit programs and better address the barriers present.

Barriers to Energy Efficiency Retrofits

The past several decades has seen considerable academic and policy focus directed at the topic of barriers to energy efficiency in the built environment [1][2][3][4][5][6]. Among these barriers, the low priority of energy issues, lack of information, upfront cost barriers, and split incentives have been highlighted as limiting the potential for retrofits in existing dwellings [7][8][9].

For the purposes of this work, the principal barriers to domestic retrofits can be summarized in three categories: upfront cost, information, and trust. The upfront cost barrier, or access to capital, is a self-evident barrier that often receives the majority of attention in policy solutions. Information is a slightly more complex barrier, as customers frequently indicated having either too much, or too little information upon which to make an informed decision. The barrier might be better described as a lack of time, as customers report rarely having the time required to filter the available information into what is useful. Additionally, the time required to plan and allow for the work itself is often cited as a barrier. Finally the barrier of trust can be disassembled into a collection of issues. Customers frequently report a lack of trust in the contractor, the program operation, or the promised savings. [10][11]

It is widely acknowledged that these barriers are pervasive and will not be addressed by any single policy mechanism or financial instrument [8]. Policies to incentivize domestic retrofits have tended to focus on specific technologies and often costly giveaways and rebates. Despite much positive progress, a significant energy efficiency gap remains [8].

An alternate behaviour model

Much recent work has highlighted the potential for behavioural economics to provide new perspectives on policy design [12]. However, historically, policies commonly rely on rational behaviour models to influence our energy use decision making and drive behaviour change.

The attitude behaviour model states that the provision of information will drive behaviour change, while the economic self-interest model assumes that individuals will change behaviour in order to maximize their own utility [10]. While these directly address the cost and information barriers discussed above, they have consistently underperformed against expectations. Both theory and practice have demonstrated that the provision of information and financing are necessary but insufficient drivers to encourage widespread adoption of energy efficiency measures [13].

CBSM builds on these theories and offers a clearer path towards enhancing communication between program designers and participants in two critical ways. It allows the delivery of targeted messaging that caters more directly to a given audience, and also enables a more interactive form of discussion that engages the end user rather simply disseminating information in a one sided manner [10]. CBSM is a methodology, not a particular outreach strategy or action. This methodology is described by Douglas McKenzie-Mohr [14]:

1. Targeted behaviour is selected.
2. Barriers and benefits associated with this behaviour are identified.
3. A strategy is designed using behaviour change tools to address these barriers and benefits.
4. The strategy is employed at the community level.
5. Program impacts are evaluated.

While these five steps describe a fairly intuitive process that is akin to improving outreach simply by reaching out to more people, the CBSM methodology accomplishes this using some less intuitive principles that draw on insights from psychology to enhance the persuasive power of the messaging. Principal among these is the idea of using social norms to reinforce group solidarity and reduce barriers to new ideas as a collective [10]. Social norms are useful because people value social relationships and therefore orient their behaviour in line with what they perceive is socially desired [15]. CBSM incorporates this idea into an outreach strategy in a fundamental way by targeting barriers at the level of social group rather than the individual [10]. It does this using the principle of the trusted messenger and the identification of leaders and authority figures within a social group. The next section will describe examples of this methodology and describe why it is particularly well suited to addressing barriers to domestic retrofits.

A new generation of retrofit programs

The CBSM methodology has been applied to a diverse range of social outreach and behaviour change campaigns. A number of studies have documented the effectiveness of CBSM towards fostering behaviour change [16] [17], as well as noted its potential applications to energy efficiency programs [18]. The application of CBSM to retrofit policies is a relatively recent, but increasingly popular trend.

The principle of establishing a program simply around the provision of information and financing faces several shortcomings. There is an accepted wisdom to the use of personalized information, relevant role-models, and personal service when engaging the behavioural aspects of energy use [19]. Some studies have indicated that the marketing and implementation of the program may even be more important than the size of the incentive [20]. It is important to note that CBSM is not a behaviour change campaign in the usual sense. Behaviour change programs typically centre on the provision of information or feedback, whereas CBSM uses these ideas to help define a more comprehensive methodology for outreach and engagement.

Financial incentives have historically targeted specific and isolated measures over more comprehensive whole-house solutions. In a national survey (n=505), people overestimated the impacts of small savings like changing light bulbs but drastically underestimated the savings realized through deeper retrofit measures such replacing appliances and HVAC equipment [21]. As this work will show, the use of CBSM can be effective at improving customer service and encouraging homeowners to take a comprehensive look at energy efficiency.

While providing giveaways and rebates are indisputably popular, they neglect to motivate those with non-financial barriers to retrofit actions. A number of behavioural studies suggest that a population is likely made up of groups with very differing, sometimes mutually exclusive motivations for pursuing retrofits, and furthermore, will have varying types of messaging and outreach to which they will be responsive [22].

It is well accepted that barriers are pervasive and must be addressed with a range of solutions [8]. Deeper retrofits require the engagement of homeowners with new feedback mechanisms, operation of new devices, adoption of new habits, and making long-term investments in their homes. All of these actions may be invisible, intangible, and grossly undervalued by the real estate industry [10]. CBSM offers a method of enhancing a programs engagement with the end user and addressing the barriers of upfront cost, information and time, and trust, more comprehensively.

Method

This work proposes to assess the application of CBSM to domestic retrofit programs on both a qualitative and quantitative basis. This will be done using two case studies from Vermont and Maine that form part of the Better Buildings Neighborhood Program.

The qualitative component of this work will explore the ways in which each program markets their services and reaches out to homeowners. This will focus on the ways in which these methods are calibrated to the specific barriers discussed in the previous section, with the aim of extracting principles that have broader applications for retrofit policy design.

The next element of this discussion seeks to define an outreach rate and an upgrade rate that will quantify the effectiveness of the marketing and outreach methods employed by each program. The outreach rate will be defined in terms of the percentage of initial program participants per household in the targeted area. The retrofit rate is defined as the percentage of program participants that proceed past the application stage and implement the recommended upgrade measures. The exact products and services included in both the initial program outreach stage and the retrofit upgrade stage varies by program and will be discussed in detail for each case study.

This work will consider the number of potential participants in the program to be the number of households in the targeted geographic region according to the most recent available census data from the US Department of Commerce [25]. The Fuller [18] review of 18 financing programs in North America employed similar criteria for potential participants, noting that this is a much larger pool than the actual potential customers. Ideally one would only include those eligible customers who could qualify for the loan and had not participated already [18]. However, the size of this smaller pool is unknown.

This work will strive to compare the outreach and retrofit rates of these two case study programs, however noting that methodological differences between them prevent a perfect like for like comparison. This is a frequent hurdle in program evaluation; however, the selection of two case studies that exist under the same Better Buildings policy umbrella allows for enough structural similarities that meaningful trends can still be extracted.

Better Buildings Neighborhood Program

Before describing the case studies with which this work explores the topic of CBSM, this section will briefly describe the policy environment within which the two presented case studies are set. The United States Department of Energy (DOE) and the office of Energy Efficiency and Renewable Energy (EERE) created the Better Buildings Neighborhood Program to improve domestic energy efficiency and drive the transformation of the retrofit market. [33]

A funding block of $508 Million USD primarily through the American Recovery and Reinvestment Act (ARRA) was awarded as competitive grants to 41 separate programs around the country. In each case, the programs applying for the ARRA funding fit into an established system of state programs already in operation. The Better Buildings portions of these programs run from September 2010 to the end of 2013[23]. This offers opportunities for comparisons across communities due to the federally determined framework and objectives set out by the DOE. This gives consistencies across program design, implementation, measurement, and evaluation [24]. This paper will consider case studies from two of these 41 programs: the Vermont NeighborWorks Program and the Efficiency Maine Trust. Before detailing the program descriptions and analysis, Table 1 gives a brief comparison of the outreach strategies employed by each program. Note that many of the outreach strategies overlap. This work will detail the differences in their implementation.

Table 1: Outreach strategies employed by Vermont NeighborWorks and Efficiency Maine.

Vermont NeighborWorks - CBSM	Efficiency Maine – Traditional marketing
-collaborating with existing NeighborWorks community group -traditional outreach: tv, radio, newspapers -earned newspaper publicity (unpaid) -town meetings -bill inserts/brochures/newsletters -events/energy parties -online/social media -phonathons -word of mouth referrals	Statewide -print media, newspapers -television, radio advertising -online/social media Local -word of mouth referrals -collaborations with contractors -collaborations with established community groups

Case Study #1 – NeighborWorks of Western Vermont

Program Description

NeighborWorks of Western Vermont is a non-profit organization founded in 1985. They are a community based social service agency created to engage homeowners in making health and safety repairs to their homes. Over the past decade they have gradually incorporated energy efficiency into part of their work scope. In 2009 they were awarded USD$4.5 million in funding from the DOE's Better Buildings grant program with the target of delivering energy efficiency retrofits to 1000 in homes in Rutland County, Vermont [26]. Rutland County has a total of 33,837 housing units [25].

The Better Buildings funding was used to establish the HEAT Squad, which is a specialized group within NeighborWorks dedicated to identifying and circumnavigating the barriers to retrofits in local groups using the community based social marketing methodology. NeighborWorks began the program with a staff of 12 people, 5 of which are now dedicated to the HEAT Squad energy efficiency program. The project hypothesized that one-on-one information sharing and greater attention to customer service could reduce or replace the need for cash incentives to drive the uptake of energy saving measures in homes [27].

The Better Buildings funding is used to create and deliver the HEAT Squad marketing, outreach, monitoring, and customer services. The Better Buildings grant is therefore not used for direct lending or rebates, but rather to drive participation in programs such as the state-wide Home Performance with EnergySTAR Program, which is separately funded through Efficiency Vermont and offers rebates on energy measures that are undertaken.

Program Process

The HEAT Squad has created a range of events and outreach activities specific to the communities in which they are operating. A HEAT Squad staff member typically guides the homeowner through the entire program process, including the selection of an appropriate contractor to carry out the work. Any follow-ups that the customer has are carried out with the same individual from the initial home audit to the final loan application process. A customer satisfaction survey (n=108) indicated that 98% of respondents were ‘very satisfied’ (84%) or ‘satisfied’ (14%) with the HEAT Squad customer service [27].

Typically, when a homeowner approaches NeighborWorks, a HEAT Squad representative will help them contact a contractor certified by the Building Performance Institute (BPI) and arrange a home energy audit. The audit is a 4-5 hour survey of the property that includes a blower door test, thermal imaging scans, and inspections of the insulation, heating, and ventilation systems. The audit identifies potential areas for improvement but does not offer any direct install measures such as weatherization or light-bulb replacements. The contractor will then issue a report with their recommendations, the potential savings, and the likely cost of the measures. Typical upgrade measures include insulation and weatherization, and heating system replacements. Should the homeowner decide to proceed with any of the upgrade measures, they will likely be eligible for a rebate offered through Efficiency Vermont. The average rebate offered by this incentive is approximately USD$1,200, and is funded via the state program, not the Better Buildings grant.[28]

While the NeighborWorks program and Better Buildings funding are not used to directly subsidize any of these measures, they have used their collective bargaining power to reduce the prices of the energy audit and thus reduce the upfront cost barrier to undertaking retrofits. Contractors typically charge USD$350-$500 for the initial energy audit. NeighborWorks have encouraged them to reduce this upfront cost to USD$100. If customers do proceed with the work the contractor will receive USD$200 in additional payment out of the USD$1,200 rebate offered by Efficiency Vermont. If customers do not proceed with any work, the contractor bears the loss for offering the audit at a reduced price; however, they typically deem this a worthwhile risk due to the increased workflow they receive through their relationship with NeighborWorks[28]. Contractors generally felt that NeighborWorks was a more trusted messenger than they could be on their own [11].

The increased workflow has resulted in the creation of 62 new contracting jobs in Rutland County. However, contractors have been cautious about the risk of taking on full time workers, so in addition, the HEAT Squad created the LaborWorks with NeighborWorks Program as an employment service with 9 further part-time contractors that can be called upon when needed.[28]

Analysis

This section will now consider the outreach rate and the retrofit rate for the NeighborWorks Program. Table 2 gives the results from the previous year using the most recent statistics available at the time of writing, as well as the total rates for the program to date.

Table 2: Outreach rates for NeighborWorks of Western Vermont in Rutland County, Vermont

Rutland County - Vermont	Past Year	Program to Date
Total Households	33837	33837
Data Period	Mar 2012 - Feb 2013	Feb 2011 - Feb 2013
Total Audits	487	1509
Total Upgrades (including in process)	195	627
Outreach Rate - Audits per Household	1.4%	4.5%
Upgrade Rate - Upgrades per Household	0.6%	1.9%

The results in Figure 1 show that the program has delivered consistent results since its debut in February 2011.

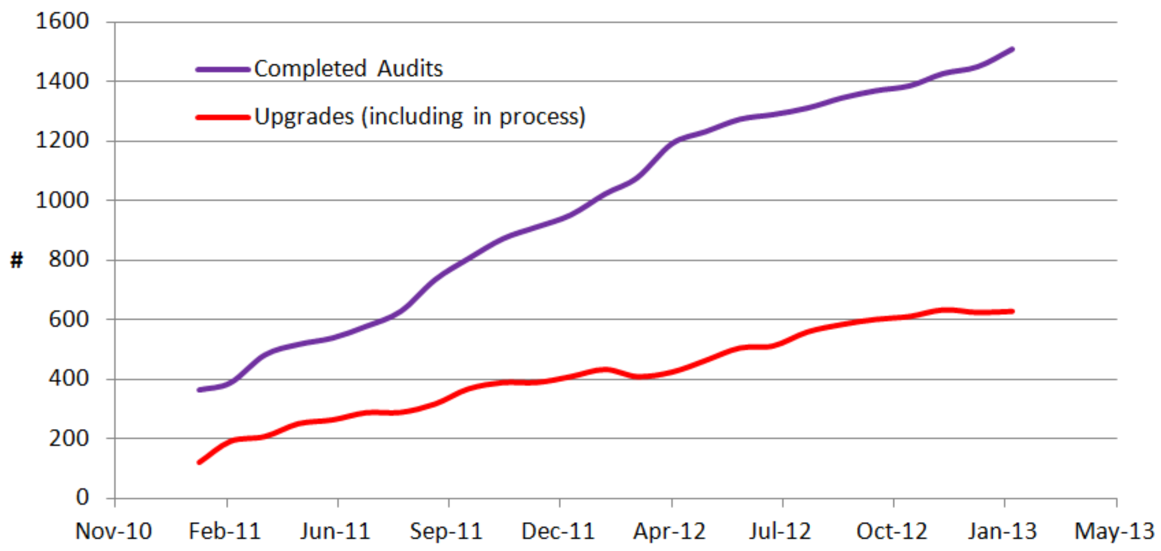

Figure 1: Audits and Upgrades under NeighborWorks program. [28]

As noted, the NeighborWorks program exists alongside the Efficiency Vermont Home Performance with EnergySTAR program. A report commissioned by the independent Cadmus Group [11] reviewed the success of the NeighborWorks program thus far. They compared the uptake of retrofit measures in Rutland County under the CBSM outreach program to those of the state-wide Efficiency Vermont program that relies on traditional outreach and media. They conclude that customers receiving the NeighborWorks messaging are 46% more likely to install measures. This was even more notable for lower income households (those earning below 80% of the average median income), where those that received outreach from NeighborWorks were 146% more likely to install measures [11].

The Cadmus evaluation also highlighted the fact that participants, including those that did not proceed from an audit to an upgrade, report a high likelihood of installing further energy-efficiency measures in the future.

Despite the fact that NeighborWorks and HEAT Squad use their Better Buildings funding for outreach and not to directly subsidize energy saving measures, the Cadmus report concludes the program delivers sufficient savings to be cost-effective on its own, with a net present value benefit to cost ratio of 1.72[11].

Case Study #2 – Efficiency Maine

Program Description

In June 2010, the DOE awarded the Efficiency Maine Trust a funding block of USD $30 million through the Better Buildings Neighborhood Program. The Better Buildings funding application was based on the funds primarily being used to finance Property Assessed Clean Energy (PACE) loans [29]. In April 2012, Efficiency Maine introduced the PowerSaver Loan Program and the Residential Direct Install Program to drive up signup rates. The programs serve a total of 725,577 housing units state-wide [25].

The program officially relies primarily on traditional outreach such as television, radio, web, and print advertising for their state-wide marketing strategy. They do however include some fundamental principles of CBSM in their local outreach when possible through collaborations with contractors or already established community groups.

Efficiency Maine commissioned an independent interim review of the ongoing PACE program [30]. From the USD$30 million ARRA Better Buildings funding, USD$20.4 million USD was used for the PACE revolving loans. PACE loans differ from typical financing by tying the value of the loan to the property not the individual. As of February 2013, a total of 158 Maine municipalities had passed PACE ordinances and entered into an agreement with Efficiency Maine to administer the loan program on their behalf, accounting for 74% of the state population. PACE loans are available in 5, 10, or 15 year terms at a fixed interest rate of 4.99%APR. Participants may borrow from USD$6,500 to $15,000, up to 100% of their home equity.

The average loan value under PACE is USD$12,898, with 50% of loans receiving the maximum USD$15,000 available [30]. Most participants were those in the top 35% of income by household. Projects below USD$7,500 are typically financed directly by the homeowner.

The suggestions in the interim program review included bundling loans with rebates, and subsidising the upfront cost of energy assessments needed for PACE loan applications [30]. These suggestions were taken onboard when Efficiency Maine introduced the PowerSaver Loan Program and the Residential Direct Install Program (RDI) in spring 2012 to expand the eligible participants. Both programs are also funded by the ARRA Better Buildings grant [30]. The PowerSaver Program covers the same home energy improvements as PACE, but offers a wider range of loan amounts, is available state-wide, and has slightly different eligibility criteria. The RDI program initially offered a USD$300 rebate towards air sealing and insulation work. In September 2012, the rebate was increased to USD$600 or six hours of work. The aim is for this to overcome the upfront cost barrier for homeowners considering retrofits. [31]

Program Process

There are two separate processes for the RDI program and the PACE/PowerSaver loan program. Customers approaching the RDI program receive a rebate for up to 6 hours of work towards direct install measures carried out by BPI certified contractors. The measures include a blower door test, thermal imaging, combustion safety testing, and air sealing and weatherisation measures. The homeowner must pay any costs out of pocket that exceed the USD$600 subsidy.

The retrofit measures targeted by the RDI program are meant to be direct install options with little follow-up or long term planning. The PACE/PowerSaver loans on the other hand begin with an energy audit that takes a more long term view at the potential retrofit measures. A BPI certified contractor will perform a survey of the possible measures including the generation of a thermal model that simulates the potential savings and payback periods. The proposed measures must demonstrate a minimum savings of 20% to be eligible for the loan.

The audit typically costs around USD$500 and is part of the loan application procedure, but does not include any on the spot improvements. The program designers hoped that customers would use the RDI direct install program as a stepping stone to the deeper retrofit measures of the PACE/PowerSaver loans. To incentivise this, homeowners may count their RDI measures as meeting the 20% energy savings threshold required for the loan, thus removing a barrier to the application process. [31]

Analysis

This section will discuss the outreach and retrofit rates for the RDI and PACE/PowerSaver loan programs. While there may be some overlap in the customer base between the two programs, these statistics are not presently available.

Table 3: Outreach rates for RDI Program

	Maine RDI
Total Households	725577
Data Period	Apr 2012 - Feb 2013
Total Outreach	2752
Outreach Rate per Household	0.4%

Table 3 gives the outreach rate for the RDI program. Since there are no follow on steps for the process, the outreach rate is simply the percentage of RDI customers per household. Note that the RDI program was introduced partway through the Better Buildings grant period to help drive further turnout. The cumulative total of RDI completions since the program’s introduction, as shown in Figure 2, demonstrates the rapidly increasing popularity of the program, particularly since the benefit was raised from USD$300 to USD$600 in September 2012. The trend suggests that the outreach rate indicated in Table 3 will increase significantly before the program's completion.

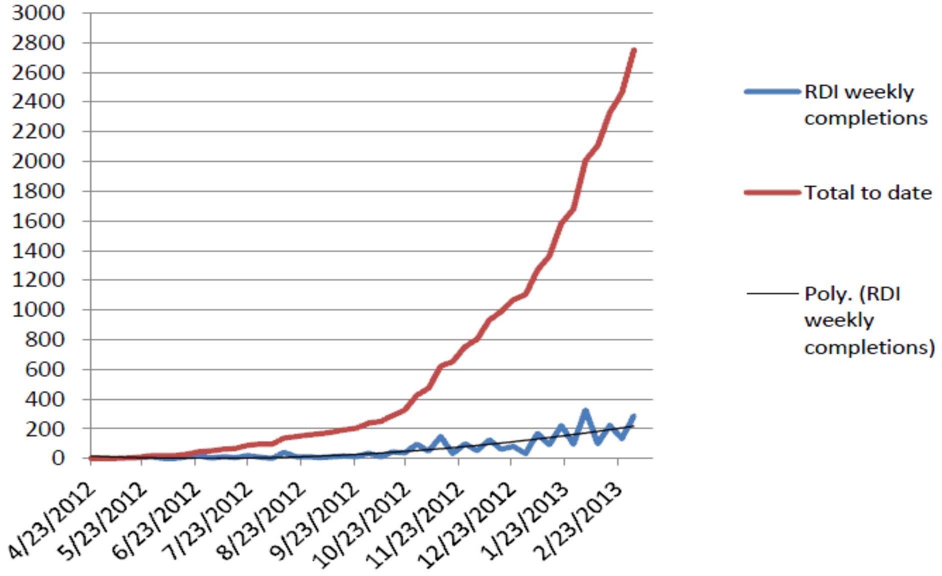

Figure 2: Number of RDI Completions.[31]

The outreach rates for the PACE/PowerSaver loan programs can be calculated in the same way as that of the Vermont program. Since the energy audit typically costs USD$500, customers seldom undertake it unless they plan to make the following step of completing the loan application. As such the completion rate from audit to application is very high and for the purposes of this calculation the outreach rate can effectively be taken as the number of loan applications per eligible household. The decrease from the number of applications to the number of upgrades is due primarily to loan applications being rejected or customers withdrawing from the process.

Table 3: Outreach rates for PACE & PowerSaver Loan Programs

Maine PACE & PowerSaver Loans	**Past Year**	**Program to Date**
Total Households	725577	725577
Data Period	Mar 2012 - Feb 2013	Jun 2011 - Feb 2013
Total Applications	1253	2003
Total Upgrades (including in process)	358	488
Outreach Rate - Applications per Household	0.2%	0.3%
Upgrade Rate - Upgrades per Household	0.05%	0.07%

With an average loan value of USD$12,838, the PACE and PowerSaver programs have closed loans totaling a value of USD$4,993,806 as of 02/10/2013.

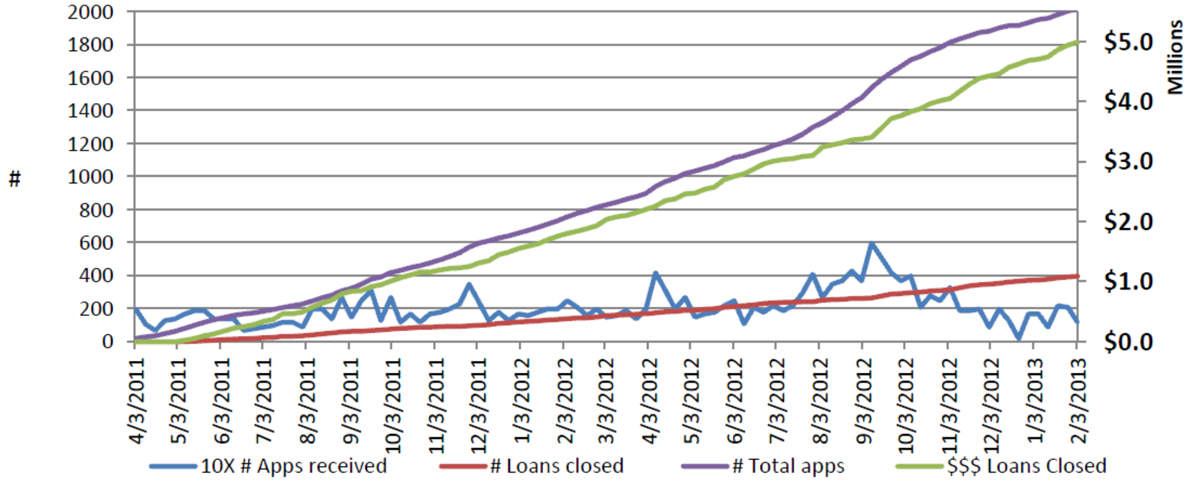

Figure 3: PACE and PowerSaver Loan Tracker.[31]

The very recent downturn in the application rate is presently unexplained. Program organizers theorize that it is perhaps due to the rapid escalation in RDI completions, and the limited resources of contractors to meet the demands of both programs simultaneously. This further suggests that if customers are using the RDI measures as a stepping stone to the deeper retrofits, then the program will likely see an imminent increase in PACE/PowerSaver loan applications.

Findings

The two case studies highlight several key ideas about the application of CBSM to domestic retrofit programs. The available data set does not permit a thorough investigation of customer motivations or a detailed analysis of free-ridership and spillover effects from other initiatives. While such methodological constraints and operational differences between programs will always cloud the potential for direct comparisons, there are some trends that can still be gleaned from the available data. Several such comparisons will now be explored in turn.

Fuller's review of 18 financing programs in North America found that on average most upgrade less than 0.05% of their potential customers in a year [18]. By this measure, both the Vermont and Maine loan programs have therefore reached more homeowners in the past year than an average loan program. Furthermore, based on the increasing outreach rates shown in Figures 1, 2, and 3, it is highly probable that the outreach rates will only improve as the programs move towards their conclusions at the end of 2013.

The NeighborWorks Vermont program utilized a CBSM approach and achieved outreach rates and upgrade rates roughly an order of magnitude higher than the Efficiency Maine PACE/PowerSaver Loan program, which relied on a traditional marketing strategy state-wide and employed CBSM principles where possible. The NeighborWorks CBSM program even delivers comparable outreach rates to the RDI direct install rebate program, which offers a higher financial incentive. Note that the link between the outreach rate and the CBSM strategy as calculated in this work demonstrates a correlation, and not a causal relationship. Nonetheless, the correlation supports the idea that CBSM is a useful tool in overcoming barriers to retrofits.

The Cadmus Report [11] included an analysis of participant motivation that was able to assign a causal relationship by comparing the results of the NeighborWorks CBSM program to the state-wide Efficiency Vermont program. They conclude that customers receiving the NeighborWorks messaging were 46% more likely to install measures and lower income households were 146% more likely to install measures [11].

The Efficiency Maine PACE/PowerSaver loan program possesses several features that enable it deliver favourable outreach rates compared to most loan programs. A significant tool is its tie-ins with the RDI direct install subsidy which lowers the upfront cost barrier. Additionally, while the program does not officially use a CBSM approach, it does incorporate several of the principles of CBSM into its marketing. The Opinion Dynamics interim report [30] observed the effective use of contractor networks and word of mouth in generating awareness of the program as well as enabling contractors to be the trusted messenger on the program's behalf.

Efficiency Maine holds monthly webinars in which it relays program information as well as training items regarding customer service and sales. This not only improves relationships with clients, but helps organize a cohesive narrative between contractors and gives unity to the Efficiency Maine brand. There are over 100 contracting firms around Maine, over half of which work with the RDI and PACE/PowerSaver programs. Over half of these participating contractors consistently attend the monthly webinars. [31]

It is noted in other behaviour change campaigns that as the sample size increases, the effect size decreases [32]. The results in this work agree with this principle. The Vermont program has roughly 5% the target population of the Efficiency Maine program and yet a similar number of total staff members. Smaller programs within tightly-knit communities have evident advantages over larger populations in delivering local and personal customer service. The success of Efficiency Maine's outreach therefore offers some useful insights in how to bring such programs to scale.

Efficiency Maine began by trying to artificially implant a community outreach structure into different community groups around the state. It created field offices and sent staff members door to door to generate interest in the program. They encountered disinterest and even resistance, and realized that their groups were outsiders and thus not suitably trusted messengers.

They therefore adopted the more traditional outreach strategy described in this paper, and turned to contractors as the focus of their community outreach. Additionally, where possible they seek collaborations with local groups that already have an established presence in their communities. Fostering these connections then allows their community presence to grow organically via the established trusted messengers, allowing them very high outreach rates in some communities. [31]

The NeighborWorks experience supports this idea, having held an established community presence for over a decade before directing their efforts to energy efficiency in recent years.

Conclusions

This work attempted to explore the application of the CBSM outreach methodology to energy efficiency retrofit programs and comment on the utility of a CBSM approach in addressing particular barriers to retrofits. It did this using two case studies of ongoing programs under the Better Buildings Neighborhood Program in the United States. These case studies were used to demonstrate qualitatively the benefits of a CBSM approach at addressing the barriers of upfront cost, time and information, and trust. Where the data permitted, the study also attempted to draw quantitative correlations between program outreach rates.

This work showed a positive correlation between the use of CBSM and increasing outreach rates, as the NeighborWorks Vermont program achieved higher outreach rates than the Efficiency Maine PACE/PowerSaver Loan program, and rates comparable to those of the RDI program which had higher financial incentives.

The Cadmus analysis of participant motivation was able to assign a causal link between the CBSM messaging of NeighborWorks and found a 46% increase in the installation of retrofit measures compared to state-wide rates. Among lower income households the CBSM outreach corresponded to a 146% increase suggesting that CBSM is particularly well suited to expanding the available audience for retrofit programs.

The Efficiency Maine PACE/PowerSaver program still achieved high outreach rates for a loan program, and the trends suggest this will only increase as the program continues to the end of 2013. The higher outreach rates of NeighborWorks Vermont enjoy the advantages of having a smaller target audience, and higher number of employees per potential customers. The Efficiency Maine program therefore offers a useful example of how to expand the principles of a CBSM strategy to a larger scale, while maintaining a state-wide outreach based on traditional marketing strategies. They did this by fostering strong relationships with the workforce and using the contractors themselves to drive community outreach. They also allowed partnerships with existing community groups to grow organically, encouraging them to be the trusted messengers, rather than trying to artificially implant a CBSM structure into a community.

This work gave examples of how the use of CBSM strategies can more directly address the barriers of upfront cost, time and information, and trust. Vermont was able to address the upfront cost barrier by collaborating with another program and using collective negotiation to create a mutually beneficial arrangement with contractors that both reduced the upfront cost for homeowners and provided additional business and created jobs for local contractors. The barrier of information and time is also better addressed with CBSM as evidenced with the high customer satisfaction rates of the HEAT Squad team compared to the state-wide results of Efficiency Vermont [11]. The barrier of trust is addressed almost by definition when employing the use of trusted messengers to deliver program information as demonstrated by Maine’s strategy in allowing relationships with trusted messengers to grow organically.

In evaluating the utility of CBSM strategies for addressing barriers to energy efficiency retrofits, one must consider many factors that were beyond the scope of this paper. Factors such as cost effectiveness, and the overall energy savings achieved are obviously critical to an energy efficiency program’s success. Furthermore, the downstream effects of different marketing strategies should be explored. Customers exposed to CBSM strategies expressed a strong willingness to undertake future retrofit work, and this effect should be investigated. The application of CBSM to retrofit programs is a relatively new development and many of the programs are still ongoing. While the long-term success of CBSM as a tool to overcome barriers to retrofits remains to be proven, the present results show much promise. Future work should attempt to break down the cost structures of various approaches to outreach and engagement and assess the implementation costs of the different programmes.

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Acknowledgements

This work forms a component of research towards my PhD thesis. I would like thank my supervisor Dr. Minna Sunikka-Blank. I would also like to thank Dana Fischer and the project team behind the Efficiency Maine Program, as well as Ludy Biddle from NeighborWorks Vermont for their support and assistance in gathering data on their ongoing works in these states. This research is supported by an EPSRC Doctoral Training Grant.

Do we know the way now? Using international comparison to confirm a policy package that can deliver energy savings from appliances

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Abstract

What are effective packages of policies and measures to stimulate energy efficiency from appliances? In the project "bigEE – Bridging the Information Gap on Energy Efficiency in Buildings", we have addressed the question in a systematic way – by combining theoretical evidence on what policy support markets need, and an international comparison on which packages of policies have worked well. The project develops an international internet-based knowledge platform for energy efficiency in buildings (www.bigee.net). Hence, it must provide evidence-based information.

On the theoretical side, presented in earlier papers, the analysis starts with the barriers but also market-inherent incentives that the different types of market participants face. This enables to identify, which regulatory, economic and other policies and measures need to be combined to overcome barriers and strengthen incentives. On the empirical side, model examples of good practice for policy packages have been collected and their design and impact compared. Finally, the model examples, lessons learned, and the preconditions for their transferability are used to validate the generic policy package identified in the theoretical analysis.

In this way, we were able to support the well-known recommendable policy package for appliances, combining MEPS, mandatory energy labelling, and information of consumers and training of sales staff, financial incentives where appropriate, and measures to stimulate innovation and market introduction such as award competitions and public or co-operative procurement, with fresh evidence. The paper will present the recommended package as well as a comparison of existing national policy packages from Brazil, China, Japan and California (USA) and what we learned from it for effective packages and implementation.

Introduction

Policy-makers worldwide have increasingly recognised energy efficiency as a key factor to reduce the energy consumption and to realise a sustainable energy future. In this context, appliances, as a major source of energy use should be a focus to control the energy consumption and to reduce greenhouse gas emissions. The most energy-efficient appliances available today can save between 60% and 85% of energy compared to inefficient models that are still on sale in many countries [19]. The energy efficiency efforts do not only achieve high energy saving potentials. CO_2 emissions can also be reduced cost-effectively from a life-cycle perspective and thus provide economic benefits. Furthermore, a policy package that concentrates on the whole life-cycle of the product can address other sustainability aspects like other resources and health aspects and realise several co-benefits like an increased competitiveness. By offering innovative products this can open up new (niche) markets, which will likely have a positive effect on the economy as a whole [8].

Yet, at least as many papers have concluded that in spite of their cost-effectiveness, these savings are not going to be realised by market forces alone (e.g., [11]; [15]). This lack of market uptake results from a large variety of barriers and market failures that hinder market actors to manufacture, sell or buy energy efficient products [18].

Therefore, the challenge remains to reach all relevant target groups and to transform the appliance sector in a way that efficient solutions will no longer be an exception but become the standard choice of market actors. We have to abandon the prevailing ‘as-fast-and-cheap-as-possible’ construction approach, because it systematically ignores lifecycle costs and creates appliances that will be wasting enormous amounts of energy and money throughout their whole lifetime [15].

To reach this goal, actor-specific and well-designed packages of policies are required. Policy-makers should be encouraged and informed to combine a selection of instruments tackling the most important market barriers.

The web-based platform “bigEE.net - Your guide to energy efficiency in buildings” was developed to make structured information easily available and to enable policy-makers to make well-considered decisions. The demonstration of the practicability of different policy approaches and the successful implementation can be a key motivation for policy makers to transfer a similar policy or to improve existing ones. The project seeks to address this problem by summarising knowledge and presenting comprehensive, independent and high-quality information on energy efficiency in buildings and appliances on its international website. In particular, the project aims to make the information about existing policies and technologies throughout the world comparable and present it in a targeted way so as to support investors and policy makers in making the right – energy-efficient – choices.

Many studies (e.g. [7]; [15]; [17]) have argued that different types of policies – most notably regulation, financial incentives and information, or “the sticks, the carrots, and the tambourines” – need to be combined into packages in order for them to be effective and make energy efficiency easy and attractive for market actors. However, we are not aware of a systematic and comprehensive analysis to underpin and derive what kind of policies and measures the packages should consist of, and how they need to interact.

To develop the evidence-based information required for bigee.net, we addressed in a different way than usual the question of how policy can support improved appliance energy efficiency most effectively: We combined (1) a theoretical, actor-centred analysis of market-inherent barriers and incentives for all actors in the supply and use chain of (energy-efficient) appliances to derive a recommended package combining the types of policies and measures the actors need to overcome all these barriers, with (2) empirical evidence on model examples of good practice policy packages to check if pro-active countries have indeed used the combination of policies we derived from the actor-centred analysis. While the actor-centred analysis has been presented during the EEDAL conference 2011, this paper focuses on the empirical evidence.

In the paper, we will therefore briefly describe the bigEE project to illustrate the project background and its scope. Next, the methodological approach to developing the recommended policy packages for energy efficiency in appliances will be presented. Then follows the resulting strategic package approach to energy efficiency policy for energy efficient appliances, proven in practice by a comparison of the existing national policy packages from California (USA), China, Japan, and Brazil.

bigEE – Your guide to energy efficiency

bigEE

Your guide to energy efficiency in buildings.

“bigEE – bridging the information gap on energy efficiency in buildings” is a project by the Wuppertal Institute, with financial support from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Within the project, the international internet-based knowledge platform “bigEE – Your guide to energy efficiency in buildings was developed (see: www.bigee.net). Three comprehensive guides – for building design and technologies, for appliance energy efficiency and for policy implementation present detailed information about how to increase energy efficiency and how policy can support this development. Apart from information universally applicable for policy makers and investors from all over the world, up to five partner countries will be addressed, starting with China and South Africa and possibly soon Mexico.

A central task for bigEE is collecting and updating information on the best available technologies (BAT) on a comparable basis, as well as the gathering of possible energy saving potentials (depending on different scenarios and market developments) and their net economic benefits, and the demonstration of successful implemented good practice policies. To achieve the required quality of information, the bigEE team collaborates with scientific institutes and with existing initiatives (international and in partner countries) including the United Nations Environment Programme (UNEP) and the International Energy Agency (IEA). Furthermore, bigEE engages in the active dissemination of information relevant for policy-makers in the partner countries.

Methodology[1]

Different steps are needed to derive an 'ideal' policy package, which increases the energy efficiency of appliances and which assist the various actors in overcoming their specific barriers and strengthening their incentives. Experience from pro-active countries and an analysis of market barriers show that several instruments will need to interact and reinforce each other in a comprehensive policy package. The question we have to answer then is which specific policies and measures should be combined in strategic policy packages to address the barriers and incentives, and how they need to interact. We used a two-step approach combining (1) an actor-centred theoretical analysis with (2) an empirical proof.

The methodological approach we use on the theoretical side is based on and seeking to extend and refine the theory-based policy evaluation approach, which goes back to experiences with energy efficiency policy evaluation in the USA (e.g., [2]) and was applied and developed further more recently within the EU project AID-EE (cf. www.aid-ee.org). Originally, the theory-based approach was developed for ex-post evaluation of existing policies. It aims at understanding how policies work and the factors of success or failure by defining for each step of implementation a theory on the implementation mechanism or strategy of the step and indicators to measure success of the step and the instrument overall. It can be used both for process evaluation and for theoretically explaining the reasons for the impact achieved – success or failure. The AID-EE project has pointed out that this can also be used to examine ex ante whether policies are expected to be successful, and therefore guide policy design. In bigEE, we developed this further to analyse, which implementation strategies and policies need to be combined to a package to achieve success in realising energy efficiency.

The actor-centred theoretical analysis starts with the identification of all relevant market actors along the value chain of the national market for the type of appliance concerned. In order to be able to adequately design and implement energy efficiency policies and measures, political decision makers must have good knowledge of the concerned market actors and thoroughly analyse the specific incentives and barriers faced by each of them. These market actors are for instance manufactures, whole sales, retailers, investors and users. All of these actors make decisions that can influence the energy performance of appliances in question.

After identifying the relevant actors in the appliances market, it is necessary to put the focus on the actor-specific barriers and incentives. All actors have some inherent incentives to develop, offer, demand or invest in energy-efficient solutions, but are on the other hand facing strong barriers that prevent them from choosing energy efficiency [6]. The challenge is to identify the reasons that cause actors to be inclined towards or to refrain from choosing low-energy appliances - these barriers are the major reason why there is a gap between potential and realised energy savings. Each actor group has its own characteristics and therefore every policy has to pay attention to these. By knowing the barriers and incentives the policy package can be adapted to guarantee desired results and achieve the greatest possible success [15]. Barriers are for example the lack of knowledge and motivation, the high search and transaction costs, the uncertainty about the related monetary and other benefits,

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[1] The actor-centred analysis was already published during the EEDAL conference 2011 (see [14]). For a detailed analysis of this theoretical approach please refer to this paper of visit www.bigee.net

capital constraints, the investor-user barrier or technical barriers. In comparison to these actor-specific barriers several incentives can be identified like saved energy costs, the increased (re-sale) value of the appliance or the contribution to environmental protection. The relevance of some of these barriers and incentives may differ from country to country depending on national circumstances [6]. Two questions remains:

- How can the immanent incentives that market actors have be strengthened?
- How can the specific barriers that market actors face be overcome?

In this context policy is needed to overcome the respective barriers and to exploit the existing potentials. For policy makers it is essential to identify the different barriers and incentives and to develop appropriate remedies in the form of tailored policy packages, which aim to remove the barriers and strengthen the incentives identified [6]. The overall goal for policy makers should be to move the market towards to the best available technology and to the best not yet available technology (BNAT) with very high energy efficiency levels. There are a number of direct ways to target the barriers and incentives. This ways can be called implementation strategies. By way of addressing the actor-specific incentives and barriers, these strategies aim to make energy efficiency feasible, easy, and attractive, and eventually even the default (i.e., the behavioural norm or even the legal standard). An implementation strategy may act on several incentives and barriers. Some examples for these implementation strategies are:

- Bring down the first costs of energy-efficient appliances via market transformation or economics of scale
- Increasing motivation by making it as easy as possible to choose the energy efficient option – make appliance energy consumption and quality visible and comparable; use social marketing tools
- Improve access to capital, e.g. subsidize purchase of energy- efficient appliances, establish innovative financing mechanisms

As a next step, political decision makers but also non-governmental actors such as energy service companies must take concrete measures and enact actual policies in order to put the implementation strategies to work. For each of the implementation strategies, a package of policies and measures is needed to make it work, and since also a combination of implementation strategies is necessary to tackle the manifold barriers, these targeted policy packages must then be merged into a consolidated overall package, which is ultimately capable of kick-starting a real market transformation in the appliance market. It is essential to have a look at the technology and the product-specific potential and to demonstrate the best way to increase energy efficiency with a package of different but coordinated instruments. Some instruments are alternative to each other, but usually several instruments should be coordinated in an adequate policy package to establish synergy effects and realise the implementation strategy.

The strategic policy package to deliver energy efficiency in appliances

According to international research and experience, a package of several types of consistent and technology-specific and actor-specific policy instruments is useful to be most successful. Instead of a single instrument, a package offers the opportunity to achieve synergies between single instruments, and to reach all market actors [15]. The ideal policy package consists of consumer-oriented instruments and instruments for manufacturers (to build a “push and pull strategy” to push consumers and manufacturers away from energy intensive practices and to pull them towards energy efficient ones). Each policy is tailored to overcome one or a few certain market barriers and to strengthen the actor-specific incentives, but none can address all of these barriers and incentives. Therefore, the impact of well-combined policies is often larger than the sum of the individual expected impact [7].

Different policies addressing the demand-and supply-side actors of markets should consequently be properly combined according to national circumstances. This does not mean that governments seeking to improve the energy efficiency of appliances have to implement all possible policies in order to be successful, but they should combine a selection of instruments tackling the most important market barriers.

As our analysis has concluded and successful countries have demonstrated (cf. also Table 1 below), a comprehensive and coherent policy package for energy efficiency in appliances will usually provide a sound balance between clear mandatory measures, incentives, information and capacity building. It also needs a governance framework to enable implementation of these policies.

The presentation starts with this overarching governance framework for energy efficiency that is general to appliances. Afterwards, the specific parts of the package with concrete policies and measures for energy efficiency in appliances follow suit.

The governance framework for energy efficiency

In the bigEE recommended policy packages, the general governance framework serves to guide and enable implementation of the sector-specific policies, as well as to remove price distortions in energy markets that would make energy efficiency improvements appear less cost-effective than they are.

A Policy Roadmap with a clear timetable and targets will guide policy-making and signal to the market a reliable political support for energy efficiency. The targets should be: Prepare markets for mainstreaming highest energy efficiency levels.

The administrative infrastructure and the funding for the other policy elements need to be in place. This includes (1) an energy agency or similar institution for co-ordinating activities. To ensure (2) stable funding, government energy efficiency funds and/or energy companies with the task to achieve energy savings via energy efficiency programmes are also required.

Energy prices should ‘tell the economic and ecological truth’. In addition, they must also consider social issues and should encourage energy sufficiency. It is essential that subsidies for energy production or on energy prices be gradually removed - governments are advised to rather use the budget saved to fund energy efficiency schemes for low-income households, so as to keep energy bills affordable instead of keeping energy prices artificially low. In addition to removing energy subsidies, energy or CO_2 taxes will finally internalise environmental damage and threats to health into final energy prices.

How the specific policies and measures for energy efficiency in appliances interact

For energy efficiency in appliances, the appliance-specific instruments can be packaged as follows:

- Mandatory minimum energy performance standards (MEPS) are the most important policy for energy efficiency in appliances. They should be created by law and then strengthened step by step every three to five years, to finally require energy efficiency levels equivalent to very energy-efficient appliances. MEPS reduce transaction costs as well as the landlord-tenant and buyer-user dilemma by removing the least energy-efficient models from the market. They should, however, always be at least as stringent as the energy performance level leading to least life-cycle costs. In a transition period before a law can make MEPS mandatory, a voluntary standard may help. Preferably, other statutory requirements, such as individual metering, would complement the legal framework.

- Energy labelling works together perfectly with energy performance standards. MEPS usually eliminate the worst products from the market but do not harness additional energy-saving potentials. Energy labels present the best products on the market and are primarily made for buyers and end-users. They are, thus, one element of the package to “reach the energy efficiency top”, like the others that follow here. Mandatory energy labelling schemes mostly compare the products on a classification scale to show the best but also the worst products on the market. Such classification labels are, however, useful only if there is a large enough spread of energy efficiency levels between the models of a type of appliance offered in a market. Where that is not the case, an endorsement label for the most energy-efficient models only may be an alternative. Furthermore, an information campaign is needed in order to promote the label and to raise the consumers' awareness towards energy efficiency.

- The market should, furthermore, be prepared for the next step(s) of MEPS regulation towards very efficient appliances through policies tackling the substantial information deficits and financing barriers. This includes the already mentioned energy labels, but also advice, easy-to-use product choice and life-cycle cost calculation tools. Policies for consumers should be designed to address specific actor groups but also the broad public. Highly consumer oriented approaches can bring energy efficiency on the agenda for many actors like end-users and investors (e.g. by TV spots or included in the school curriculum). Such programmes can address the rebound effect. These effects occur when consumers buy bigger and bigger appliances, such as large televisions of refrigerators or when they improve their desired thermal comfort (e.g. higher indoor temperatures in cold seasons). Policymakers should try to limit these rebound effects e.g. through motivation and information campaigns on energy-efficient user behaviour.
  Financial incentives - such as rebates, grants and tax incentives – can guarantee a broad market introduction of energy-efficient appliances. The latter are more costly than other instruments, so they will be particularly useful if there is a very large spread of energy efficiencies in the market and, hence, large energy cost savings are possible. In addition, they can often be limited to a certain time period (e.g., two or three years) until the market offer and demand has switched to the energy-efficient models. For low-income households, financing support may be needed to purchase very energy-efficient appliances that have a higher upfront price but pay back over their lifetime through lower energy bills.
  Policies, which can be perfectly combined with education and financial instruments, are policies addressing the life-cycle of the product including other sustainability aspects like resources, recycling and health. It is mainly for such information and financial programmes that energy efficiency funds or energy companies must contribute.

- Education and training of professionals (manufacturers, sales staff, and other relevant market actors) should prepare introduction and further strengthening of MEPS regulation. Certification of successful participation to the training can make it more attractive for both the qualified market actors and their customers.

- Once a certain market share of (highly) energy-efficient appliances is reached, the professionals are trained and used to selling the energy-efficient models, and the cost-effectiveness of the next step is proven, then this level can then be mandated by the regulation to become the new MEPS level.

- Future steps of MEPS regulation towards very energy-efficient appliances should be prepared by innovation support through R&D funding, award competitions, and maybe also already by financial incentives for broad market introduction. The public sector should lead by example through energy-efficient public procurement, thereby paving the way for the other sectors to follow. To push the market further towards energy-efficient appliances and create first markets for them, co-operative procurement programmes can make an important contribution towards very efficient products due to the high purchasing power. Voluntary agreements with large buyers to purchase more energy efficiently than required by MEPS may also support market introduction.

The following figure illustrates exemplarily a comprehensive policy package for appliances and describes the interactions between minimum energy performance standards, energy labels, financial incentives, energy-efficient procurement, RD&D (Research, development and demonstration) promotion as well as education and training programmes.

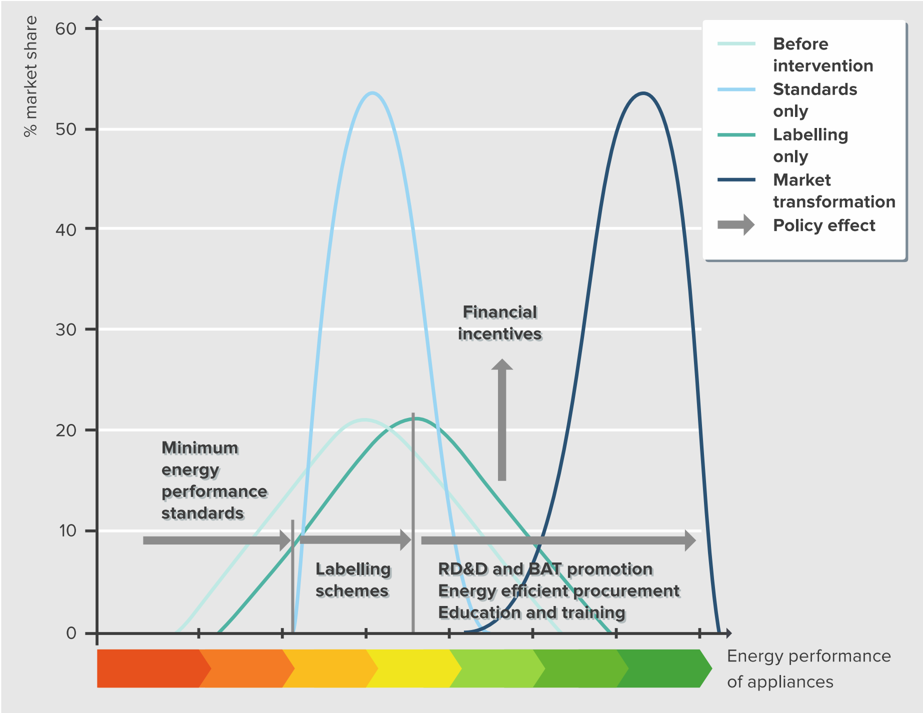

Figure 1: The interaction of policy instruments for energy efficiency in appliances

Source: Wuppertal Institute 2012

Model examples of good practice policy packages

The next step of our above mentioned methodology was to find out whether the results of our theoretical analysis are consistent with actually implemented examples of successfully operating policy packages. Consequently, we had to search for empirical evidence of good practice packages in pro-active countries. This next step was therefore the analysis of the policy packages that a number of countries have actually implemented to provide the empirical proof. Therefore the country analysis was to check whether the main elements of the theoretically adequate policy package can indeed be found in real life in the policy packages of advanced countries, so as to confirm the composition of the package. However, this does not yet include an assessment of whether all of the policy elements these countries have combined to their package are good practice for themselves.

This search started from a number of publicly available databases (such as International Energy Agency, World Energy Council, the EU project ODYSSEE-MURE[2]) and was continued with in-depth literature review on candidates identified by the team and international experts we approached for advice.

As some pro-active countries show (cf. Table 1), the policy package that we derived from our actor-centred analysis is exactly what these countries have introduced to approach very high levels of energy efficiency in appliances. These can be considered good practice for the consistent packaging of policies; however, more research is needed to analyse whether each element is a "good practice" policy of its kind and which country has achieved the biggest progress towards very energy-efficient appliances. The table can thus not be read as giving any statement on these further questions.

Table 1: Comparing the recommended policy package with good practice from four countries

Category of policies and measures	Subcategory of policies and measures	Implementation in California, USA	Implementation in China	Implementation in Brazil	Implementation in Japan
Governance framework					

[2] www.iea.org/policiesandmeasures/energyefficiency/ ; www.wec-poliicies.enerdata.eu ; www.odyssee-indicators.org

Energy efficiency targets and planning	Policy roadmap and targets for very efficient appliances	Assembly Bill 32, Climate Change Scoping Plan and Long Term Energy Efficiency Strategic Plan (Updated 2011)	China has a programme for mandatory minimum efficiency standards	National energy plan 2030, the Energy Efficiency Act	Basic Energy Plan, Energy Conservation Law
	International cooperation	California is part of the Western Climate Initiative, Co-operation with the Province of Jiangsu in China	China cooperates with the US Environmental Agency and with the Energy Management Corporation of South Korea	International organisations helped raise the profile of energy efficiency, substantial contributions from other countries	Japan is member of the IPEEC, EMAK, GSEP, Green Purchasing Network, JICA organises several activities
Infra-structure and funding for energy efficiency programmes and policy	Energy agencies	State level: California Energy Commission and California Public Utilities Commission; Federal level: Environmental Protection Agency, Department of Energy	National Development and Reform Commission (NDRC)	National Electrical Agency	Agency for Natural Resources and Energy (ANRE) Energy Conservation Centre of Japan (ECCJ)
	Overall co-ordination and financing	Each utility company must provide energy efficiency programmes and services: Energy Efficiency Portfolios and Budgets approved by the California Public Utilities Commission; Public Goods Charge	The Ministry of Finance is the key player in terms of funding; NDRC, CNIS and CSC are also instrumental for implementation	There are different financing schemes: Funding comes from the Public Benefits Funds, ELECTROBAS, the ANEEL Energy Efficiency Programme, PROESCO and other programmes to support energy efficiency	ANRE, ECCJ, NEDO agencies and budget by METI
Eliminating distortions	Removal/reduction of subsidies on end-user energy prices and on energy supply (if they exist); Energy/ CO_2 taxation and emissions trading	The electricity rate is divided into tiers	China plans to gradually implement a carbon trading system from 2013 on		There are some energy taxes but not a emission trading or a carbon tax
	Regulation of energy companies	Cost recovery of energy efficiency programme costs plus performance-based incentives; Decoupling of energy company profits from sales;		Regulatory supervision of the use of the Public Benefits Funds;	
Specific policies and measures					
Regulation	Minimum energy performance standards (MEPS)	MEPS were implemented in 1977; currently "2010 Appliance Efficiency Regulation"	China has a programme for mandatory minimum efficiency standards	Federal Law 10.295 MEPS	
	Other legal requirements				Top Runner Program, Home Appliance Recycling Law, Agreement to reduce stand-by power consumption
Information	Mandatory labelling scheme	Energy Guide	Energy Information Label	Mandatory A-G labelling scheme, Energy Standard Information System	Uniform Energy Saving Label

				(ESIS)	
	Voluntary labelling scheme	ENERGY STAR	Voluntary Energy Efficiency Endorsement Label	Voluntary labelling scheme PROCEL	Energy labelling programme; ENERGY STAR for office equipment
	Provision of targeted information	Product database for customers ENERGY STAR programmes, Flex your power	EE Information week, consumer education programme, online appliance databases	PROCEL provides relevant information on experiences and success	School programmes, training courses, up-to-date information, "Energy efficient household appliance forum", product database
	Feedback and other measures targeting user behaviour	Opower			Energy Conservation Navi Smart Life
Financial incentives and financing	Financial incentives	Financial incentives are given by both private and public energy companies. For example, SCE offers a rebate on refrigerators if an ENERGY STAR product is purchased, Energy Management Assistance Program	There are plans to subsidise the purchase of energy-saving refrigerators and other appliances	Refrigerator replacement programme	Eco-Point Scheme
	Financing instruments (e.g. soft loans)				
Capacity building & networking	Education & training for supply chain actors	Training of retail sales staff (ENERGY STAR – Retailer Resources)	GEF Project: Chinese manufacturers participated in design training workshops, study tours, and expert technical assistance	PROCEL offers training courses, seminars and conferences	Energy education in schools; Training of retail sales staff by retailers under the Energy Efficient Product Retailer Assessment Program
Promotion: Research, Development & Demo and Best Available Technology	Public sector programmes ('Lead-by-example', energy-efficient public procurement)	FEMP - EEPP	In 2006 the legal requirement „Energy Efficient Products For Government Procurement" came into force	Targets for the public sector	Green Procurement Law
	Research and development funding	Public Interest Energy Research programme		The Ministry co-ordinates research and development projects	NEDO is the largest R&D management organisation, METI has some R&D programmes
	Competition and awards	SERP, Super-efficient Refrigerator Program	The GEF project introduced the „principal award" The programme also included a lottery-style purchaser award		Energy Efficient Product Retailer Assessment Program

Note: the table only shows the priority types of policies in the bigEE recommended policy package

Source: bigEE analysis (online including all types of policies and all sources at www.bigee.net)

Discussion: What the countries do vs. bigEE's recommended policy package

A look through the table confirms that the empirical evidence proves the composition of policy package developed with the actor-centred theoretical analysis and presented above to be the right combination of policies and measures.

The governance framework for energy efficiency

Although all four countries have designed a roadmap facilitating the efficient use of energy, there are some notable differences. California stands out because of its long-term commitment to decrease GHG emissions by 80% of 1990 levels by 2050 set out in the Climate Change Scoping Plan (CCSP), which together with the Long Term Energy Efficiency Strategic Plan signals reliable political support for energy efficiency. Expanding and strengthening appliance standards are considered "key elements" [12]. For the medium-term, Assembly Bill 32 legislates GHG reductions by 2020. Similarly, China has been legislating energy intensity targets since its 11th Five-Year-Plan, established 2005, which is supported by Medium and Long-Term Energy Conservation Plan. This plan, however, does not go beyond 2020. Brazil's and Japan's strategic plans cover a period until 2030.

In Brazil and China, the Ministry of Mines and Energy and National Development and Reform Commission, respectively, pave the way towards an energy-efficient future. However, at least for Brazil, there is much room more for improvement in terms of allocating financial and human resource. California's Energy Commission (CEC) was, among other things, established to promote energy efficiency through appliance standards. Together with the Utility Commission, closely supervising privately owned energy companies, CEC designs energy efficiency measures. In Japan, the Agency for Natural Resources and Energy (which is under the Ministry of Economic, Trade and Industry) and the Energy Conservation Centre of Japan are the most important actors for increasing energy efficiency.

Brazil, California, China as well as Japan have realised that market distortions negatively affect rational energy consumption. However, different approaches have been pursuit. In California utilities are required to promote energy efficiency programmes to end-users funded through the Public Goods Charge. Moreover, energy companies are obliged to participate in a cap-and-trade programme on GHG emissions, which incentivises them even more to engage in energy-efficiency measures for end-users (e.g. refrigerator rebates). Because the less energy their clients consume, the less emission certificates need to be bought. The Chinese government plans to gradually implement emissions trading system nationwide and Japan introduced the Carbon Tax in 2012, whose funds are used for energy efficiency and renewable energy measures. Through this scheme, end-users are to use energy more rationally due to increasing energy costs. Brazil's government legislated utilities to invest 0.5% of their annual net revenues in end-user programmes aimed at increasing energy efficiency. Half of that sum must be spend on low-income households

Specific policies and measures for energy efficiency in appliances

Minimum energy performance for appliances is a key issue for all four governments, stressing its significance within an appliance package. While a comparison of the country-specific standard-setting processes would go beyond the scope of this paper, a brief description of Japan's innovative Top-Runner approach seems to be appropriate. Simply put, the Top-Runner programme identifies the most efficient appliances (or the top runners) of an appliance category on the market. Their energy efficiency value is applied as a future minimum energy efficiency standard to be achieved after a transition period of three to twelve years. This period is determined by taking into account technological development forecast and the development period of products. "Because the standard is based upon data from existing products, it can be said that the standard is market driven, i.e. no standard is set that is not (yet) available in a product on the market" [10].

Each of the four governments utilises mandatory and voluntary labels in order to accelerate market transformation by providing consumers with transparent and comparable information about the energy consumption of appliances. In Japan, the most energy efficient appliances can reach five stars. Only Japan's voluntary label, which can be incorporated into the mandatory one, shows a) whether a products meets the respective standard, b) in how far (in %) the device performs better or worse than its standard and c) how much energy a given product consumes. China's label classifies appliances into five different categories, from class one (highly efficient) to class five. Similarly, Brazil scales devices from class A (highly efficient) to class G. Both are reminiscent of the EU Energy Label and also make use of a voluntary label. The U.S. stands out because it does not incorporate a classic classification scheme. It rather focuses on the estimated annual operating costs. This suggests that the U.S. Government considers the lack of consumer information regarding the operating costs of devices a main barrier towards market transformation. On the upper end are operating costs for highly efficient devices and energy-inefficient devices (available on the market) constitute the scale's lower end. In terms of worldwide implementation, the voluntary label of the USA, the Energy Star, can be considered a huge success. Japan, the EU and other countries have made use of the Energy Star for a broad range of appliances, for office equipment, in particular. However, the Energy Star label is not very ambitious and the requirements are not based on the best products on the market. The label is also used for the public procurement in the USA but the function is mainly to set minimum energy performance standards. By this, it only cuts the most inefficient products from the market.

In order to make consumers more fully aware of energy-efficient appliances, all four governments provide information through different information campaigns. Feedback measures such as the Energy Conservation Navi in Japan or the Home Energy Report, offered by Opower in California (and other U.S. regions and countries), are to inform the end-users more comprehensively about their energy use and can be considered an asset for both cases. California, China and Brazil support or supported the purchase of some energy-efficient appliances. Particularly in Brazil, low-income households are focused on. The Japanese Eco-Points programme is like the Top-Runner approach a very innovative measure. Eco-points can be received for the purchase of appliances that, at least, score four stars on Japans mandatory energy label.

Education and Training programmes for supply chain actors are implemented in each of the four cases. However, capacity building measures in China, which were supported by the Global Environment Facility, can have a very positive effect. First, China's sales figures for the domestic market rise constantly (Fridley 2008, p.5). Second, increasing energy efficiency in products made in China, will improve energy performance of devices worldwide.

All governments also seem to acknowledge the usefulness of public sector programmes. Whereas California, China and Japan introduced public procurement law, Brazil's commitment to only "consider" energy efficiency in the procurement process appears to be a less ambitious. Research and development funding programmes are implemented in all cases but China. Regarding competition and awards, Brazil poses an exception. China, again, benefits from the GEF project, which, among other things, announced a reward of USD 1 million to the manufacturer achieving the greatest total energy savings.

Discussion: What are the achievements?

As noted before, the comparison between these four cases served as an empirical proof for the composition of the recommended policy packages for energy efficiency in appliances. Still, one question remains. Can these four cases also be considered successful in terms of energy saved? And what has been the contribution of policy packages? Unfortunately, information that would make the countries' achievements comparable is not easily available, if at all. To compare the four governments the following impact analysis focuses on cold appliances.

- Between 1977, when the USA fired the starting gun for energy-efficient policy measures, and 2001 the maximum allowed energy consumption of a typical fridge-freezer has dropped from 1,546 to 476 kWh/year. Further reductions are expected. An indicator showing the success of the policy package may also be the stabilisation of electricity consumption (per capita) at around 7,000 KWh since 1978. This stagnation contradicts electricity consumption of the USA in general (1978: ~9,000 kWh/capita, 2008: 12,000 kWh/capita) [3].

- With regard to China, the bigEE-analysis focused on refrigerators, freezers and combinations of the two. Sales figures rose from 360,000 devices in 1999 to 46 million in 2008. Between 2008 and 2010 the market share of Grade 1 appliances increased dramatically from below 10% to 77%. As far as China's mandatory energy label is concerned, it is estimated to have the potential to save more than 16 TWh by 2020 alone [5]. Due to continuous economic growth, that may become more inclusive in the near future, sales figures for appliances are likely to rise, which makes a comprehensive policy package aimed at reducing energy consumption of appliances even more important.

- The Brazilian government achieved to reduce the average energy consumption of new refrigerators from 491.3 kWh/yr to 270.4 kWh/yr between 1990 and 2005 [1]. Moreover, regarding the Brazil's voluntary label, PROCEL, established in 1993, saved 22 billion KWh by mid-2008 [9].

- With the Top Runner Program, Japan achieved an energy efficiency improvement rate of 55.2% from fiscal year (FY) 1998 (647.3kWh/yr) till FY 2004 (290.3 kWh/yr) for electric refrigerators. The expected average energy consumption for the target year for refrigerators was 449.7 kWh/yr [13]. For 2010, a study expected further energy savings of 21% for refrigerators and 12.7% for freezers compared to 2005 levels. Actual efficiency improvement is 43.0% from FY 2005 (572kwh/yr) to FY2010 (326kwh/yr) especially for large refrigerators and 24.9% for freezers.

Information on impacts resulting from energy-efficient policies and policy packages, in particular, are highly diverse. However, the cases discussed have implemented a broad range of policy instruments that are necessary to overcome barriers and strengthen incentives to achieve an energy-efficient appliance stock. As has been shown, developed and developing countries can make such important steps. However, more needs to be done and, hopefully, bigee.net can guide future measures for an energy efficient future.

Conclusion

With the two-pillar approach to policy analysis used here, we have been able to add new foundation, both theoretical and empirical, to the conclusion about what is a necessary and advisable package of policies to effectively advance high energy efficiency improvements in appliance:

As the first pillar, the actor-centred approach to policy analysis has confirmed our presumption that there is not one silver bullet that will kick-start a real energy efficiency transformation in the appliance sector. What is urgently needed are consistent packages of policies and measures, carefully tailored to the needs and incentive structures of all actors in the appliance value chain. Our theoretical analysis along this value chain has given us good insight as to which implementation strategies can successfully tackle the many existing barriers and which combinations of policies are needed to put these strategies into practice. The first important result is thus the policy packages we now recommend on bigee.net. There are sometimes alternative policies for one strategy, so the final composition of the package will depend on the circumstances in a specific country.

As a secondary result, we have also advanced the methodology that governments and consultants can use to assess given appliance markets and the policy support that all relevant actors need to harness energy efficiency.

As the second pillar, we also ascertained that the main elements of the theoretically adequate policy package could indeed be found in real life in the policy packages of advanced countries. This does not yet include an assessment of whether all of the policy elements these countries have combined to their package are good practice for themselves. But it confirms the composition of the package.

During our research on such model examples, we found, however, that the lack of thoroughly documented and evaluated policies and measures (both for single policies and for sectoral policy packages) makes the search for good practice quite difficult. Accordingly, resulting from our analysis there are two key messages for policy makers planning to implement a new policy or measure: it is crucial already in the policy design phase to bear in mind both the actors concerned and the data needs and other requirements in terms of monitoring and evaluation of the impacts, costs and benefits as well as for compliance with the policy, in order to ensure its effectiveness.

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The Practical Scope for Reducing Air Conditioning Energy Consumption in Europe: Policy Opportunities and Priorities

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Abstract

For a variety of reasons, market penetration of air conditioning and consequently demand for cooling in Europe continues to increase and on a "business as usual" basis would increase by over 50% by 2020, although recent economic events may result in a somewhat smaller increase.

This paper summarises the results of an extensive "Study to assess barriers and opportunities to improving energy efficiency in cooling appliances/systems" carried out by the Building Research Establishment and funded by CLASP. The purpose of the study was to contribute to the development of relevant policy by identifying and quantifying the potential impact of possible measures to reduce the energy consumption of air conditioning in Europe over a ten year period, relative to a business as usual case.

Many of the policy measures relate to the performance of products and equipment, but there is also considerable potential in the areas of load reduction and more effective operation and management of systems. The analysis focuses on quantified realisable savings that reflect technically feasible measures whose rate of introduction is constrained by the replacement rate of air conditioning systems and appliances, refurbishment rates of buildings and different levels of ambition for performance regulations placed on air conditioning equipment and systems. It is disaggregated by country, but this paper concentrates on results for Europe as a whole.

The measures that offer the largest realisable savings formed the basis for recommendations for policy measures, often using existing policy instruments. These measures fall into two groups relating, on the one hand, to policies that impact directly on technical requirements for systems and products and, on the other hand, to those that do not. The second group includes policy measures to incentivize effective operation of buildings and systems, and to influence take-up rates for high-efficiency products.

Additional recommendations relate to the application of policy: consistency of approach between instruments; choice of application at national or European level. The report also identifies areas where further work is needed to improve the robustness of studies similar to this one.

More detailed results and information about the study can be found at
http://www.bre.co.uk/searchresults.jsp?category=5&q=energy+management

Introduction

This paper assesses the realisable potential for reducing energy consumption in Europe over a ten-year period by analysing a number of idealised cases which represent different types of possible measure applied with different ambition levels. The cases which yield the largest potential savings are identified, routes to implementation are discussed and recommendations to support implementation are offered.

The market for air-conditioning in European building is immature in the sense that ownership in most countries is considerably lower than in equivalent climates in North America or the Far East. (see, for example [1] This is reflected in the fact that most sales are for first-time installations in new or existing buildings with relatively few replacement sales. [2] This is very different from the markets for most other forms of building services, such as heating or lighting, where most sales are replacements.

The empirical evidence is that market penetration has increased fairly steadily over several decades with only a few signs of saturation [2] [3]. In consequence, consumer demand for cooling is likely to increase and, other things being equal, so is the associated demand for mainly electrical energy. However, there are many opportunities for reducing demand and improving the efficiency of use. For example, in a growing market, the impact of high-efficiency products is more immediate than in a market where the penetration of efficient products is constrained entirely by the replacement rate. In the study underpinning this paper we have also sought to engage with a wide range of policy options for constraining the growth of air conditioning energy consumption, including minimum performance requirements placed on products, on systems and on whole buildings and their systems. This broad perspective implies a more integrated approach to the development of policy, mobilising in a more deliberate way a comprehensive set of policy elements to form an integrated policy package.

The European market for air conditioning products and systems is far from being homogeneous. Consequently, the same is true of the installed stock of systems. Cooling demand varies with climate and with building type. New building may have higher (or lower) cooling requirements than existing ones. Different types of air conditioning system are more convenient to install in new or existing buildings, and for use in simple or complex buildings.

Categories of Systems

European product policy reflects the recognition that air conditioning systems designed to provide comfort in buildings can be divided broadly into three categories, with different principal applications and supply chains.

- Moveable units: These are appliances bought over the counter or on-line and do not generally require any installation expertise. These appliances are mostly used in dwellings and small commercial buildings.

- Room air conditioners/Packaged systems: These are series-produced self-contained units or systems comprising a unit that conditions a single room. They should generally be installed professionally. These systems are used in both commercial buildings and dwellings.

- Central systems: These are larger systems that serve more than one room (often large numbers of rooms or an entire building). They are generally bespoke systems designed for specific buildings, but are largely composed of standardised component products. In Europe they are predominantly used in non-residential buildings. There are a number of different types of central system, each with particular areas of applicability. For example some types of system are difficult to install in existing buildings.

Categories of Energy Saving Measures

There is no shortage of opportunities for reducing the energy used for air conditioning. Energy saving measures fall into three general categories: reduced loads, higher technical efficiency and improved operation.

- ***Reduction of cooling loads*** through improved building design and construction, and through the use of more efficient appliances and lighting systems.
  - The range of economically feasible measures relating to building design is more limited in existing buildings than in new designs. Some measures can only be practicably applied to existing buildings as part of major refurbishment works.
  - Cooling demand reductions from more efficient appliances and lighting often result from energy-efficiency measures specifically directed at those products.

- Improve the ***technical efficiency of air conditioning systems.***
  - Moveable units and room air conditioners are series-produced products to which performance tests and minimum requirements can be applied in a similar way to other energy-using products.
  - It is more difficult to devise practicable performance metrics for central systems, which are essentially bespoke. Such metrics can be applied in principle to specific components, but in-use energy use is often dependent on the design of the system as a whole. For example, energy use for air movement is often substantial in central systems and is, to a large extent dependent on the design of the air distribution

system. Component replacement is more frequent than complete system replacement

- ***Reduce wasteful operation*** of air conditioning systems.
  - In principle, this category of measure is immediately and universally applicable. In practice its application is often constrained by a shortage of easily assimilated information and pressure on building managers to prioritise other operational problems.

Policy Instruments

There are a variety of policy instruments that can be deployed to reduce the consumption of energy for air conditioning, including mandatory minimum performance requirements applied to products, systems or buildings; information provision, including energy labelling; financial incentives and energy pricing. Different instruments bear on different types of system, and on different categories of measures. Some instruments can only be practically applied at a Member State (or region or municipality) level while others are more suitable for a European level of application. The mapping of policies onto the most important cases is discussed later in this paper.

Realisable Savings

Realistic objectives for energy saving must take account of a range of practical constraints, not least the relatively long lifetime of air conditioning products and systems and the long time interval between major refurbishment of buildings. This study assessed “realisable savings” that would accrue over a ten-year period relative to a business as usual base case.

A ten-year period is sufficiently long to include the growth rates of the markets for: new systems in existing buildings; new systems on new buildings; replacement systems; product and system turnover rates; and building refurbishment rates. It is sufficiently short to constrain uncertainties due to long-term market projections; changes in policy priority; and changes in technology and pricing. During a ten-year period most of the initial stock of room air conditioners and moveable air conditioners will have been replaced, but a significant proportion of the original energy-using components of central systems will remain in place at the end of the period. In addition, many buildings will not have undergone major refurbishment during this period. In consequence there is considerable remaining potential for savings from building-related load reductions and from the complete replacement of central systems as part of major refurbishments.

Analysis Approach and Data Sources

General approach

This section of the paper provides an overview of the modelling process and data sources.

The core of the analysis is explicit, disaggregated modelling of energy consumption for a range of different assumptions, denoted “cases”. The modelling takes into account the replacement rate of air conditioning systems and appliances, refurbishment rates of buildings and rates of market growth. Levels of realisable savings were estimated for different levels of ambition for performance regulations placed on air conditioning equipment and systems, for practicable load reductions, and for improvements to operational efficiency.

We have calculated savings as if policy instruments were introduced instantaneously at the start of the period (the base year for the modelling is 2010.) This is obviously not realistic, but provides directly comparable estimates and avoids the complication of assessing the timescale for policy to be agreed and implemented. In addition, national data were sparse for some countries with smaller market potential and it was necessary to make estimates based on parallels with other apparently similar countries. For example, the figures for Norway are derived from market statistics for Sweden, scaled for population. The realisable savings are therefore to be viewed as idealised indicators of the scale of savings that are possible within the 10-year time frame.

The model generates estimates of annual energy consumption for the cooling and air movement functions of air conditioning systems. The calculation is disaggregated in a number of ways:

- Country
  - In order to capture the different national market dynamics, climates and national energy requirements for air conditioning, each of the EU-27 Member States and the EEA countries was separately modelled.
  - This paper, however, focuses on the EU-wide results.
- System type
  - The three broad categories described above were further disaggregated into 14 specific system types.
- Building type
  - Buildings of different age and use have different cooling demand levels. It was not practicable to include all building types and ages.
  - The stock was disaggregated into the three types of building that market research revealed to represent the largest shares of equipment cooling capacity: dwellings, offices and retail buildings. Each of these was represented in both a new-build and existing building form.

Air conditioning system energy consumption was calculated for a ten-year period for each combination of country, system type and building type, based on the aggregate installed cooling power, the aggregate air conditioning system efficiency characteristics, and the climatic and building design features were specific to each combination. This was repeated for both a base case and a number of variant cases which included energy-saving measures.

28 different combinations of plant (system energy performance), fabric and equipment energy saving measures were modelled, representing different energy saving measures and levels of ambition (for minimum performance requirements for example). Some cases represented combinations of measures since the combined impacts are not simply additive. These cases represented typical operating practice: the impact of more effective system operation and management was then explored as variations to these "technical" cases. A separate analysis explored the theoretical scope for savings if less-efficient types of existing central systems were replaced by more efficient alternatives (separately from simply replacing components).

Methodology overview and data sources

Stock and sales

The existing and future stock of air conditioning systems drew on previous studies by the authors [2] [3], The general approach was to obtain historical sales figures from market research sources, and by a process of fitting these to a market diffusion equation for each country and comparing reported proportions of sales in to new buildings, first-time sales into existing buildings and replacement sales, to build up sales trajectories and levels of installed cooling capacity. Aggregate floor areas of cooled space were not explicitly estimated, as suitable data sources are extremely limited. However, the resulting base case estimates of total energy use for air conditioning are consistent with published assessments based on floor area estimates which are summarised in the "results" section below).

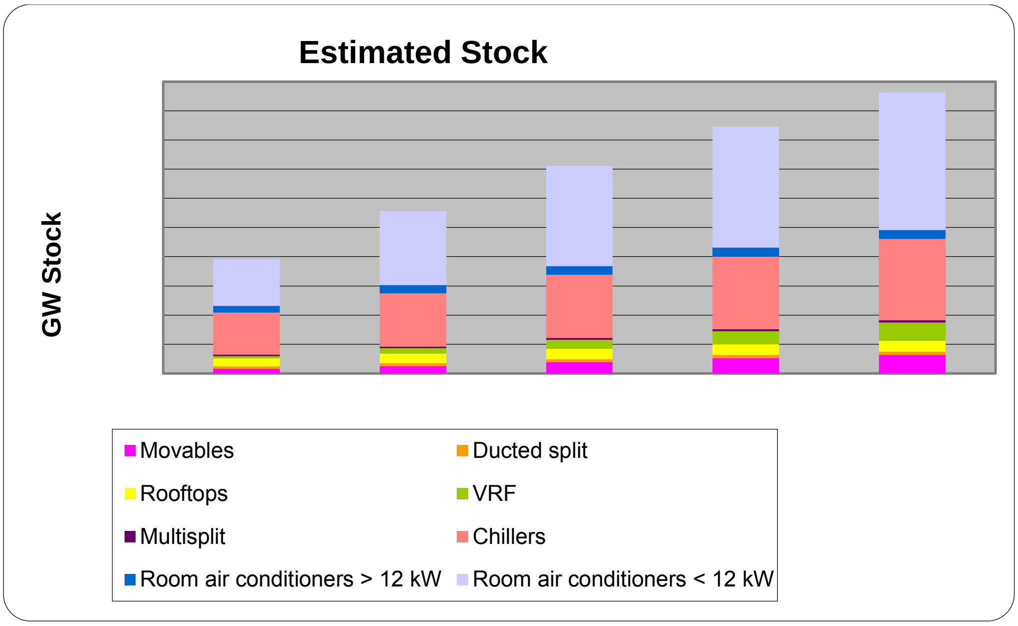

Figure 1. Installed cooling capacity (EU-27, ref [2])

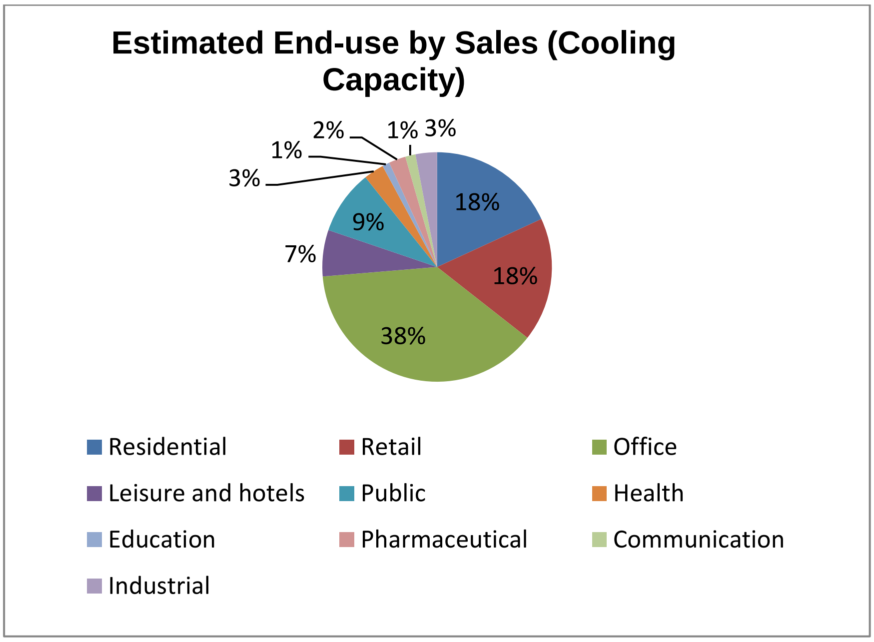

Figure 2. Sales by end-use (cooling capacity) (EU-27, ref [2])

System energy consumption and efficiency

In order to estimate annual energy consumption from the installed aggregate cooling power it is necessary to first estimate the load factor or "equivalent full-load operating hours" (EFLH) of the cooling plant.

The energy efficiency of moveable and fixed room units is defined by a seasonal energy efficiency ratio value (SEER) for a standard climate. In this project the values reflect the specific standardised climate assumptions of the ESEER metric. [4] The estimated energy savings for these products are derived from modelled changes in the mixture of products of different SEER in the installed stock of systems.

Central systems cannot be adequately represented by a single efficiency metric, not least because there are a number of system configurations and within each general configuration there are variations to match the needs of the specific building in which they are installed. The energy modelling is consequently also more complicated. The calculation procedure uses a set of algorithms originally developed for use in software for the implementation of the European Energy Performance of Building Directive (EPBD): SBEM [5] [6]. The software was developed specifically to estimate annual energy consumption taking into account *inter alia* HVAC system characteristics, and consequently has different objectives, structure and capabilities from software developed primarily to support detailed building design. The annual consumption of each combination of system, building, and climate is estimated by combining the total installed cooling power with an aggregate seasonal energy efficiency ratio (SEER) of the cooling plant and with a number of system characteristics that can lead to energy wastage [7]. These characteristics include: fan energy consumption as a function of specific fan power (itself a function of ductwork design), heat energy gains from fans, heat transfer to distribution duct- and pipe-work, control imperfections and duct leakage. For the UK, it produces energy consumption figures that are a close match to empirical benchmarks, including energy use for air movement associated with the air conditioning system. In this study the fan energy used to supply outdoor air (for ventilation) has been separately accounted: air movement for air conditioning is the additional air movement that is used to distribute cooling in some system types. The cooling algorithms have been modified to allow the use of different climates and design conditions. The basic UK load factors (expressed as equivalent full-load hours) for each building and climate combination are consistent with empirical consumption benchmarks. For other countries, they have been modified to reflect differences between building types and climates by scaling them according to the results of previous building simulations carried out by the University of Athens in support of Ecodesign projects. In addition, stand-by and off-mode consumptions have been added.

A general flow diagram for the central system model shown below in Figure 3 illustrates the structure of the central system model.

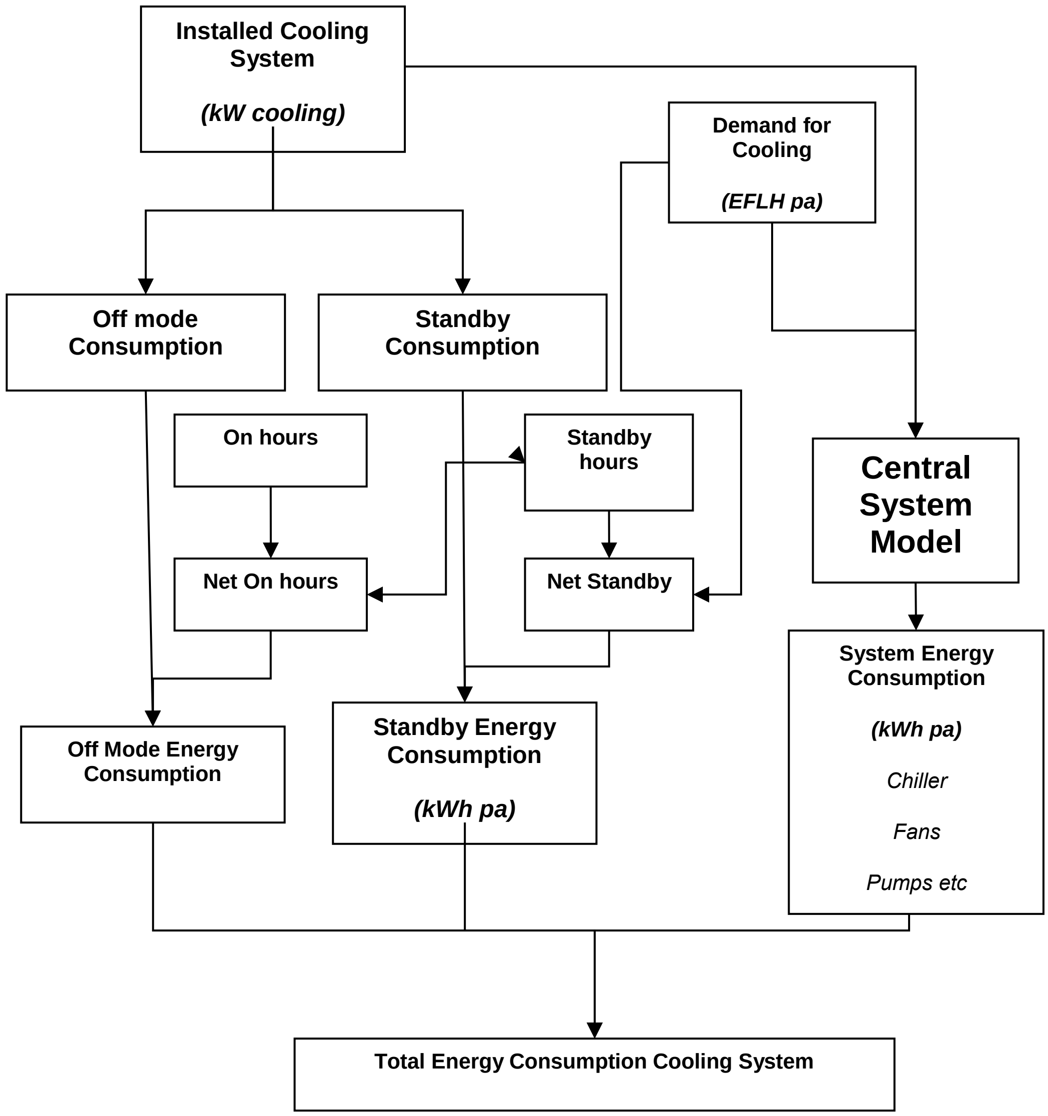

Figure 3. Schematic of Central System Model

Aggregate SEER values for products were derived where possible from the distribution of values weighted by sales figures for each product type. More commonly, sales-weightings were not available and aggregate figures were estimated from the distribution of products listed on the Eurovent database, [8] converted from EER values where necessary. An example of the source data is shown in Figure 4 below.

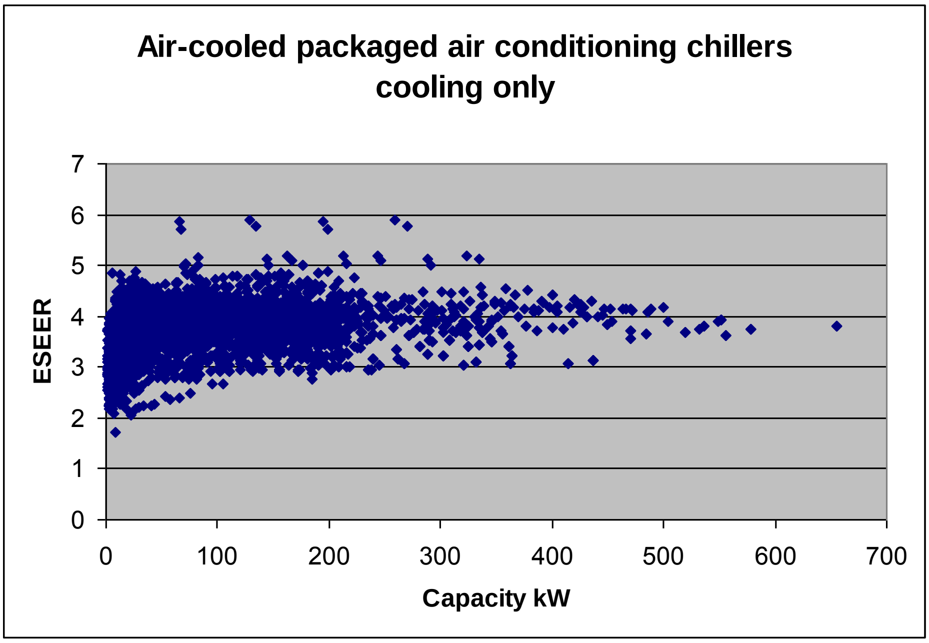

Figure 4. Example of ESEER distributions (air-cooled chillers)

The impact of energy efficiency measures such as minimum performance requirements and energy labelling on the aggregate SEER values were represented by changes to the relative frequencies of products of different performance.

Similar processes were used to estimate other parameter values.

Load Reduction Measures

The principal data sources for estimates of load reduction – both from building envelope measures and from the use of equipment and lighting systems with reduced heat gains – were two previously published studies: KeepCool [9] and Harmonac [10].

The KeepCool project assessed the potential for reducing cooling demand in existing offices across Europe from a number of measures in the following categories:

- Reduced solar gain
- Enhanced ventilation
- Improved equipment and lighting efficiency
- Reflective surfaces and added insulation
- Windows

The study assessed the potential savings by carrying out energy demand simulations for example buildings to which various load reduction measures had been applied in each of five climate zones across Europe. The results were generalized by the KeepCool project assigning each country to one of the zones.

The KeepCool study used energy simulations to assess the potential savings in example buildings in each of five climate zones across Europe. The results were generalized by the KeepCool project by assigning cities in each European country to one of these climate zones.

In the present study, these results were taken to represent the theoretically available savings if there were few practical implementation barriers (including cost). In practice, this theoretical potential is constrained by practical and financial constraints. These constraints were represented in the present study by using additional information from the Harmonac project. The Harmonac project carried out detailed assessments of the practical potential for reducing air-conditioning energy consumption in 42 "Case Study" air–conditioned buildings, including but not restricted to office buildings. The frequency with which measures appeared in these buildings was taken to represent a "technically feasible" level of implementation which might be included in new buildings or in existing ones during major refurbishment.

A second, lower, estimate of realisable savings was developed from the Harmonac project. The project carried out several hundred inspections of air-conditioned buildings in order to determine what energy saving opportunities were identified and the time required to identify them. These were much less detailed studies than for the Case Study buildings, carried out by air-conditioning technical staff (who were briefed to look for demand reduction opportunities) and identified fewer measures, and generally lower-cost variants (for example adding shading film to windows rather than external shading). These measures, and the frequency with which they were identified, were used to represent the effect of generally feasible and identifiable measures.

The impact of the load reduction measures was represented by reducing the EFLH figure to represent the (aggregate) reduction in consumption.

Improved system operation

The EFLH figures used in the energy consumption calculations are consistent with empirical benchmarks and therefore implicitly reflect typical usage. The inspections and Case Study analyses carried out by the Harmonac project confirmed that there is often substantial energy wastage through imperfect operational practices: such as poorly-set temperatures controls and time clocks, missing controls and filters that are in need of cleaning.

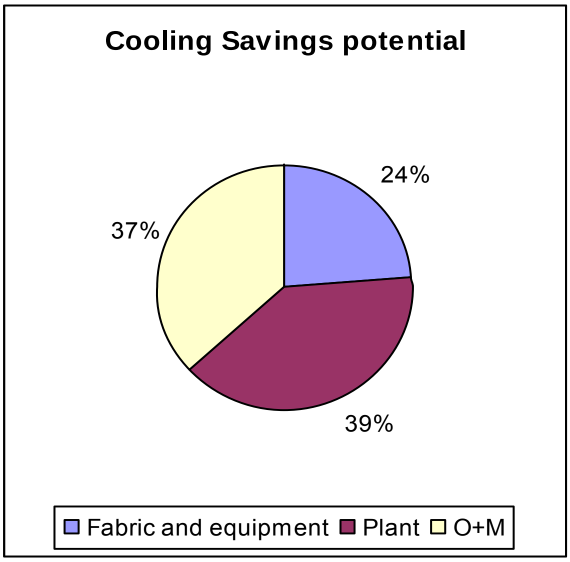

Figure 5. Harmonac Summary of Types of Cooling Energy Saving Potential

The empirical estimates of potential savings from this project were used to estimate the potential savings from better operational practice. "Practically realisable" savings were based on additional results from the project that identified what proportion of this theoretical potential was actually identified by air conditioning inspections.

Cases Examined

The cases examined included the introduction of different levels of minimum performance requirements (including "best available technology"), with and without energy labeling and with and without financial incentives for each of:

- Seasonal energy efficiency ratios for
    - Movable air conditioners
    - Room air conditioners
    - Central system chillers
    - Complete central systems
    - Central system fan coil terminal units

    - Central system pumps
- Specific fan power factors for central system air handling units
- Air leakage requirements for ductwork and air handling units
- Reduced fresh air requirements to reflect smoking bans
- Load reductions from building and equipment improvements
- Measures to improve operational management of systems

The possible take-up rate of measures will clearly be different according to whether they apply to first-time installations of products or systems, replacement products or systems, new buildings or existing buildings. This is reflected in the modeling of the theoretically realizable 10-year savings. In particular, the rate of implementation for measures that would not realistically be likely to be introduced except as part of major refurbishment was controlled by assumed refurbishment rates.

Principal Results:

Base Year: comparison with other estimates

Table 1 compares the estimated aggregate energy consumption for the base year from the present study with figures from other studies and shows generally good agreement, given the different definitions of scope used and the different dates of estimates. The Ecodesign Studies use a similar approach as the present study, while the other figures are derived from estimates of air conditioned floor area and consumption per unit floor area.

The figures in this section relate only to the annual consumption in the base *year* – although this study uses base case covering a ten-year base period, comparable figures are not available from other studies.

Name of Study	Total estimated Annual Energy Consumption TWh pa	Comments
This study	76.91 (moveables+ Room ACs + central systems) plus 63.6 for air movement energy consumption (140.5 cooling and air movement)	“Air movement” excludes that attributable to fresh air supply
EcoDesign Preparatory Studies [12].[13],[14]	Cooling only: 38.6 (Lot 10 but for earlier year) + 74 (Lot 6) = 112.6 Ventilation (not only associated with air conditioning) 100 TWh [1]	Ventilation figure includes use in non-air-conditioning applications
EECCAC study [4]	94.7	EU-12 only, 2003
Harmonac study [10]	198	
Electricity Consumption and Efficiency Trends in European Union - Status Report 2009, European Commission Joint Research Centre Institute for Energy [14]	38.6	Appears to only include room units < 12kW (Lot 10 study)

Table 1. Comparison of estimated annual air conditioning energy consumption for EU from various studies

[1] This figure is not explicitly stated in the report but has been inferred from data in the report)

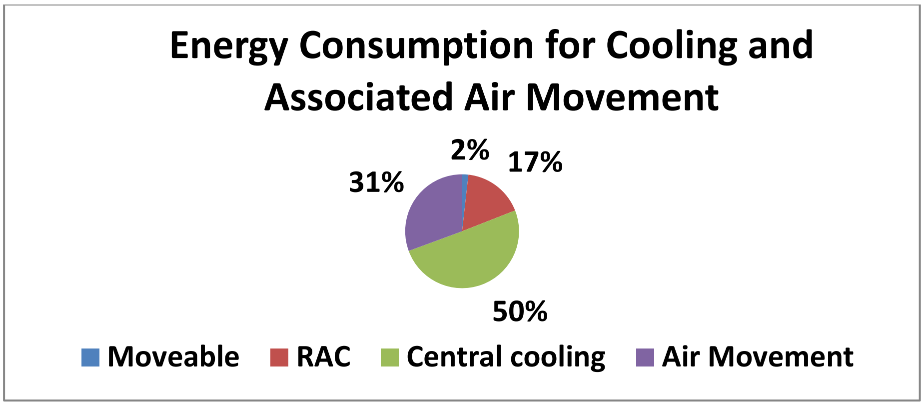

Figure 6. Summary of Energy Consumption for Air Conditioning: Base Case, EU-27

The relative contribution of central air conditioning systems compared to the distribution of installed cooling capacity shown earlier is the result of the higher distribution losses (and energy needed to offset fan energy heat gains) associated with this type of systems. As can be seen, the energy associated with air movement in centralised systems is substantial.

Base Case and Theoretical Potential Savings

In the base case, the market penetration of air conditioning increases but no new energy saving measures are introduced. Existing policies such as energy labelling of room air conditioners and movable units are included in the base case.

From the modelling, we have estimated that universal application of the best available technology and practices in the three categories of energy-saving measures might, in theory, reduce consumption by up to 80%. The maximum realisable ten-year reductions approximately 10% of the base case.

Summary of Principal Results

The seven cases that generated the largest estimated energy savings over 10 years are illustrated below. In most cases there are energy savings related to both the cooling and air movement functions.

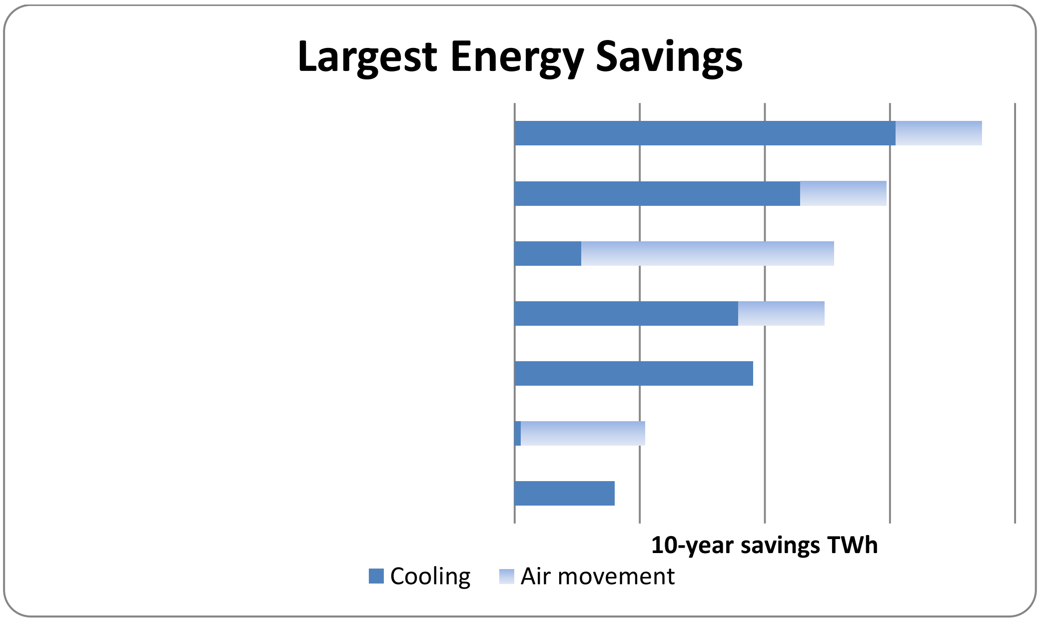

Figure 7. Summary of the Cases showing the largest Realisable Savings

These high-potential cases impact on all three of the types of energy saving mechanism, but it is noticeable that all have some bearing on system efficiency and only one directly addresses operational practice. The number of “X”s indicates our subjective view of their relative impact on the different forms of saving. Thus improved specific fan power can have a major impact on system efficiency through the reduction of fan energy use but a much smaller impact on the cooling load placed on the system (through reduced heat pick-up from fans).

Case	**Impacts on:**		
	Cooling load	System efficiency	Operation
Minimum performance requirements integrating building and system characteristics	XXX	XXX	
Detailed energy audits of air conditioning systems	XX	XX	XXX
Reduced fresh air in spaces where smoking is now prohibited	XXX	XX	
Minimum energy performance requirements for complete systems		XXX	
Demanding minimum performance requirements for chillers		XXX	
Performance requirements for specific fan power and air leakage	X	XXX	
Demanding minimum performance requirements for room air conditioners and other packaged units		XXX	

Table 2. Relationship between Principal Cases and types of Energy Saving

As noted in the previous section, in many of the cases, the 10-year take-up for some savings is constrained by the likely refurbishment rate of existing buildings. In particular major changes to central air conditioning systems (apart from component replacements) and to the building fabric are unlikely except as part of major refurbishment. As a result further savings beyond the 10 years period can be expected for most of the high-impact cases. Few further savings beyond the 10 year period will occur for minimum performance requirements for room air conditioners (of which many existing products will be replaced within the ten-year period), nor for energy audits (we have assumed mandatory application and good take-up of recommendations). The effect is present, but to a lesser extent for minimum performance requirements applied to air conditioning chillers, which typically have operating lives of the order of 20 years, resulting in a significant number of older products still being in use after ten years.

Some measures occur within more than one case – though not necessarily with the same ambition levels – and there are also interactions between measures. The savings from each are therefore not simply additive.

Discussion of Principal Results

Minimum performance requirements integrating building and system characteristics

Scope

This case represents the application of minimum performance requirements to the combination of the building and its air conditioning systems and products, applied during initial design and major refurbishment. It also assumes that minimum performance requirements are applied to replacement air conditioning systems and products, albeit at a less demanding level than assumed in the case for product requirements alone. This combination permits designers to meet the performance requirement by trading off different forms of energy saving according to the specific needs and circumstances of each building. As a proxy for this flexibility, the modelling assumes a combination of moderately demanding performance requirements for systems and load reduction mechanisms.

Specific buildings could, of course, combine more demanding performance in some areas with less demanding performance in others.

Implementation Method

This case follows the principles of the EPBD minimum performance requirements for buildings. As it has to be applied at the level of individual buildings, practical implementation has to be by Member States – most conveniently using the framework of their existing building energy regulations or standards.

Implementation Issues

The savings estimates assume that every Member State has relatively demanding (but not extreme) ambition levels. This is far from certain, notwithstanding the cost-optimality requirements of the EPBD Recast.

As far as is known, only a few Member States building energy regulations apply minimum performance requirements to replacement air conditioning products and systems. The movement towards the introduction of such requirements for products, through the Ecodesign Directive will partially address this gap, though the levels of requirements for products that can be justified for single-market products that may be used in many different climates and applications might be problematical.

A more fundamental barrier is that few Member States' regulations contain detailed calculation methods for the seasonal energy consumption of air conditioning systems. In a survey by the EPBD Concerted Action [15], only 6 of the 15 respondents claimed to have such a calculation method. Where calculation procedures do exist, Member States have largely developed them in isolation from each other and there is a need for a recognised and practicable methodology. A practicable methodology needs to be compatible with the rather low data reliability for existing buildings and systems, balancing the complexity (or otherwise) of calculation against the uncertainty of the data. It should also, as far as possible be consistent and make use of experience with those methods that are already in use.

Recommendations to support implementation

- A consensus should be developed for a generally acceptable energy consumption calculation procedure, which should then be developed and tested.
- Member States should be required to implement an effective calculation procedure.
- In order to support the application of such calculations, energy labelling requirements for air conditioning products should make mandatory the public provision of the part-load data used to define the label.

Detailed energy audits of air conditioning systems

Scope

This case assumes the mandatory implementation "detailed energy audits". These are more detailed – and more costly - site investigations than the "inspection" that is required by the EPBD, In addition to more detailed physical inspection and testing of systems it includes an element of consumption monitoring and associated diagnosis. EPBD inspections have been shown to identify only a small proportion of potential energy savings, albeit these are usually easily-implemented low-cost measures. It is the only case offering substantial savings through improved energy management.

Implementation Method

Since this measure has to implemented at an individual building level, implementation has to be by Member States. A number of Member States already have active programmes of Energy Audits which offer a model for general implementation.

Implementation Issues

Energy audits are not cheap, can intrude on business operations and savings are not guaranteed. Implementation of the less costly, but less effective EPBD inspections has been slow and is widely seen as not being cost-effective. The most effective combination of measurement, analysis and physical inspection is uncertain. The use of remote monitoring as an adjunct to inspection or auditing is currently being investigated [16]. In order to achieve savings, identification of opportunities has to lead to actions, some of which may incur significant costs.

Recommendations to support implementation

- Review existing Member States' energy audit programmes and policies
- Investigate the use of electronic monitoring of air conditioning systems to improve the cost-effectiveness of inspections and audits

Reduced fresh air supply to spaces where smoking is now prohibited

Scope

The supply of outdoor air for many existing air conditioning systems was designed in the anticipation that occupants would be permitted to smoke. In many buildings smoking is now no longer permitted. There is scope for new systems to have lower ventilation energy requirements than older ones, and also for many existing systems to be modified to use lower outdoor air supply rates. This leads to reduced fan energy consumption and, to a lesser extent to reduced cooling demands to deal with hot outdoor air and to offset heat released by the fans.

Implementation Method

Since this measure has to implemented at an individual building level, implementation has to be by Member States. For new systems fresh air rates in design guidance should be reviewed. The energy saving opportunity should be brought to the attention of building operators and air conditioning system inspectors.

Implementation Issues

The savings for this case are rather uncertain since the number of air conditioning systems designed for spaces where smoking is permitted is uncertain and the extent to which Member states have banned smoking is poorly documented

Recommendations to support implementation

- Fresh air design rates and regulatory requirements should be reviewed in the light of smoking legislation and amended where appropriate.
- Air conditioning inspectors should be reminded of the potential for savings.

Minimum energy performance requirements for complete systems

Scope

This case assumes the mandatory application of minimum energy performance requirements for air conditioning systems: in practice central systems, since packaged units and movable air conditioners are series-produced self-contained products that can be subject to Ecodesign requirements. This would apply to new installations in new buildings, new installations in existing buildings and replacement systems.

Implementation Method

Central systems are, in essence, bespoke systems using more or less standard components. They are tailored to match the needs of individual buildings and implementation has to be by Member States. For new buildings and major refurbishments this can be through national building energy regulations and standards, but the scope of these does not necessarily include the installations of new systems in existing buildings.

Implementation Issues

Although this case offers the potential for substantial realisable savings, there are several implementation challenges. The absence of a suitable calculation methodology discussed above applies equally to this case. In addition, installations in existing buildings are commonly outside the remit of national building energy regulations and codes, and additional infrastructure to implement the measure (or an extension of the remit of national building energy regulations) would be needed. For example, either installers or contractors will need training, or they would be required to employ accredited specialists in order to demonstrate compliance. This is not impossible but would add an extra workload onto a structure that is already heavily loaded.

With the exception of new installations in existing buildings, the benefits can more easily be gained through the "*Minimum performance requirements integrating building and system characteristics"* case discussed earlier. Minimum performance requirements for air conditioning components such as chillers would capture a proportion of the savings potential of new systems in existing buildings and it seems debatable whether the advantages of this case justify the need for extra support infrastructure.

The EPBD Recast specifically calls for the introduction of minimum performance standards for technical building systems but does not specify how these are to b implemented.

Recommendations to support implementation

- Air conditioning system-level performance requirements should not be treated as priority issue, but the case for them should be reviewed from time to time.

Demanding minimum performance requirements for chillers

Scope

This case applies demanding minimum energy performance requirements to air conditioning chillers.

Implementation Method

Chillers are series-produced products and can be subject to Ecodesign requirements including minimum energy performance requirements.

Implementation Issues

A Preparatory Study [11] was released in 2012 (after the work summarised in this paper was completed) that makes the case for such requirements. The recommendations are currently being considered. A potentially difficult issue for European product performance requirements for air conditioning products is that the performance levels that can be justified vary, in principle between climates and applications. Demanding requirements – if they incur extra costs – may not be cost-effective for relatively mild climates and national requirements ma offer better value for money than a single Europe-wide requirement. The performance levels proposed by the Preparatory Study are cost-effective for most European climates, at least for the building type considered (although only very marginally so in milder climates).

Recommendations to support implementation

- Introduce mandatory energy labelling and MEPS for chillers
- Before introducing Europe-wide demanding levels of product minimum performance requirements, consideration should be given to implementing them via national building codes, accompanied by an over-riding but less demanding European minimum performance requirement.

Maximum specific fan power requirements and leakage requirements for air handling systems

Scope

A significant proportion of the energy used in air conditioning systems is for air movement. This case assumes the universal application of requirements to limit air leakage from ductwork and to limit fan energy use. The metric for the latter is “specific fan power” and is a characteristic of the air handling system as a whole. It is determined by a combination of ductwork design, air handling unit design, (including cooling coil design and filter specification) and fan and fan motor efficiency.

Implementation Method

A number of Member States have such requirements within their national building energy regulations and standards. This case makes such provision universal.

Implementation Issues

A Preparatory Study into the application of Ecodesign [12] requirements to ventilation products has recommended an alternative energy performance metric for air handling units. This metric relates to the product (the air handling unit) alone and characterises its performance under standardised operating conditions. It therefore ignores the important contribution to energy consumption made by other parts of the air handling system and, from the wider perspective of system performance is incomplete.

Recommendations to support implementation

- Minimum energy performance requirements for specific fan power should be introduced in those Member States that do not already have such requirements.
- Minimum energy performance requirements for ductwork and air handling unit leakage should be introduced in those Member States that do not already have such requirements.
- To assist Member States to introduce these requirements, model clauses and guidelines should be developed, based on the experience of those that already have them

Demanding minimum performance requirements for room air conditioners and other packaged units

Scope

This case considers the implementation of demanding minimum energy performance requirements for room air conditioners and other packaged air conditioning systems.

Implementation Method

From 2013 minimum energy performance requirements for room air conditioners of less than 12kW cooling capacity (the majority) have been implemented under the Ecodesign Directive [14]. The Requirements will be made more demanding in 2014.

Implementation Issues

The analysis supporting the current requirements was carried out some time ago and, notwithstanding some revisions, is less demanding than those assumed in this case. In the meantime, the range of high-performance products on the market has expanded substantially. In some countries, sales of high-efficiency units have also increased significantly. As in the case of chillers, universal requirements for demanding performance levels may not be cost-effective in some milder climates.

Recommendations to support implementation

- Evaluate the case for progressively making the minimum performance requirements more demanding.

Supplementary recommendations relating to the principal results are summarised in table 3 below.

Case	Recommendations and relevant Policy Instruments		
	EPBD	**National Building Energy Codes** *(may be implemented via EPBD)*	**EcoDesign Directives**
Minimum performance requirements integrating building and system characteristics	Develop agreed air conditioning system efficiency calculation procedure		Provision of part-load information
Detailed energy audits of cooling systems	Stronger implementation of current requirements	Explore use of automatic performance monitoring	
Supporting actions for energy audits	Report calculated system efficiency on EPC Report measured air conditioning energy consumption Expand use of measured energy ratings		
Reduced fresh air in spaces where smoking is now prohibited		Review of outdoor air requirements	
Minimum performance standards for air conditioning systems	Introduction of system MEPS		
Demanding minimum performance requirements for chillers			Introduction of MEPS
Performance requirements for specific fan power and air leakage		Wider introduction of requirements	
Demanding minimum performance requirements for room air conditioners and other packaged units			Review MEPS
Generic Recommendations		Consider combination of EU and national MEPS	
Recommendations for further work	Investigate effectiveness of information provision measures in business to business supply chains Investigate relationship between product price trends, energy performance and MEPS		

Table 3. Summary of recommendations (including supplementary recommendations)

A note on cost-effectiveness and ambition levels

The results discussed above relate to the cases which generate the largest 10-year “theoretically realisable” energy savings. In practice they represent relatively demanding levels of ambition embedded policy instruments that either already exist or seem to us to be feasible. Equivalent cases with lower levels of ambition were also examined but are not reported in this summary paper.

Deciding what is an appropriate level of ambition is clearly an important policy decision, but is no simple matter. While the general direction of travel of policy is reasonably clear, the pace of change and justifiable levels are not.

A rational choice of appropriate measures and ambition levels depends, amongst other considerations, on their expected cost-effectiveness. However, the concept and definition of “cost-effectiveness” are also less clear-cut than is often assumed. From a policy perspective, for example, cost effectiveness can be viewed from the perspective of the direct costs faced by building owners and operators, or from the costs and benefits to society as a whole. Regulatory intervention may be justified for measures that are cost effective for society but not from the end-user perspective. Broadly speaking, the “demanding" performance levels referred to above reflect measures that are currently likely to be seen as cost effective by a only few building owners and operators in a limited number of building types and climates, but are – in our opinion - .plausibly likely to become cost-effective for society in general in the foreseeable future.

This section discusses a number of issues that surround (and often complicate) the definition of cost-effectiveness.

These two different perspectives are both important, but for different reasons. Ideally both need to be taken into consideration. Unhelpfully to the development of consistent policy, practice differs between different pan-European and National policy strands relating to energy use for air conditioning.

The two perspectives are:

- The perspective of society as a whole, including shadow prices for externalities (such as damage inflicted by climate change) excluding taxes and subsidies, using a (low) social discount rate.
- The perspective of end-users. This perspective includes taxes and subsidies, excludes non-priced impacts and uses commercial interest rates. Typically this only justifies lower performance levels than the societal perspective

Commonly both types of assessment are based on a hypothetical “typical” user and do not take account of different levels of impact on different parts of society. In the context of air conditioning, this could be users resident in different climates, for example.

From an economic perspective, in principle, all energy policy packages and measures should be designed to be cost-effective to society as a whole. However, policy measures that can be justified from this perspective may seem uneconomic from the perspective of some, or all, end-users. This situation is often used to justify the imposition of state regulation.

In practice, the cost effectiveness of product MEPS in Europe is generally assessed from that of an idealised end-user (who, somewhat inconsistently, is usually assumed to take a perspective that reflects the whole life of the measure and to apply a social discount rate). However, for building energy standards and regulations, the perspective differs between Member States. Roughly equal numbers of countries apply either a societal perspective or an end-user perspective, but a significant number consider both perspectives. Renewable energy policy generally takes a societal perspective.

For consistency of policy making it would be desirable to have an agreed set of conventions. The proposed EPBD methodology for cost-optimal building energy standards could be, in principle, a suitable basis for this but has become unnecessarily complex, yet still incomplete.

A common objective of policy design is that measures should be cost-effective or cost-optimal [2] . A policy is *cost effective* if its costs are less than the value of the resulting benefits. Cost effectiveness is sensitive to the assumed price and performance of the “base case” with which potential measures are compared. A policy is *cost-optimal* when the net benefits are maximised. This is a stronger requirement.

Many of the data needed for cost effectiveness calculations are inherently uncertain. This is most obviously the case for future prices (of, for example, energy) or of “shadow” prices (such a carbon damage price) for which there is no empirical evidence.

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[2] And improved energy efficiency should not be at the expense of other aspects of performance such as comfort or noise.

For product and system performance policy there is the extra complication of possible interaction between the introduction of minimum performance requirements and product prices. Engineering analysis for products in the USA [17] show ratios of between 0.5% and 1.5%, with the higher figures relating to higher performance equipment. Calculations in Preparatory studies for Ecodesign [11] show a similar range. Japanese product prices [18] suggest that a 1% improvement of efficiency is associated with a 5% increase in price, but that some of this results from non-efficiency factors. Equivalent figures at less demanding performance levels from China suggest a somewhat lower effect.

The impact on market prices may, however, be different since there may be compensating reductions in the cost of stocking and supply resulting from the higher volume of high-performance product sales (and the removal of low-performance products). Non-mandatory high-efficiency products may also command higher prices by being positioned as "premium" products with additional features such as self-cleaning filters.

An IEA report [18] not specifically dealing with air conditioning) concluded that "Although there appears to be no correlation between price and energy efficiency and the average price of appliances has been falling consistency, there is evidence that the most efficient products in some categories are more expensive than products which are less efficient." Some of this increase was thought likely to be due to the inclusion of non-energy-related features in "premium" products. However, "the commercially sensitive nature of pricing policies, together with the complexity of separating out pure efficiency costs from other appliance features, makes it difficult for an outside observer to understand how prices relate to costs of manufacture"

Thus while the idea that policy should be guided by some kind of assessment of the costs and benefits of that policy is generally accepted, *what* costs and to *whom* is the subject of continuing scientific, methodological and political discussion.

Concluding remarks

In this paper we have quantified the growing energy, economic and environmental challenge arising from growing demand for cooling. A significant technical potential for reducing the projected growth in the associated energy demand has been identified at the component, product, system, whole buildings, and operational level. A comprehensive menu of recommendations assembled on how existing and new policies can be mobilised, in an integrated manner, to help curb the projected rise in energy consumption from air conditioning.

Acknowledgement.

The work summarised in this paper was funded by CLASP. The conclusions and any errors or omissions are the responsibility of the authors.

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Enhance energy efficiency, technical and marketing tools to switch people habits in the long-term

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Abstract

Electricity consumer behaviors are known to be both hard to change and unstable. From this point of view a state of the art of smart-grid experiment and an overview of Home Energy Management Systems show that after a first phase of enthusiasm and energy efficient efforts, the moves cool down. Equipped people tend to take back their habits or to let the system run on its own, giving no more consideration to energy saving actions. Several cases even show a rebound effect, where people consume more energy that before the system was launch.

In order to keep people focused on their own energy efficiency behavior and help them to make the effects more long-lasting, the Grid-Teams project, held in 2012 in the city of Cannes, French Riviera, decided to focus on nudge marketing to assess whether these kind of services could enhance user's loyalty on efficiency habits.

By *nudge marketing*, we mean several tools to help users to understand and act. The experimentation helps them focus and to fully handle their own electrical impact. For this purpose, we metered forty households and built a complete Web user interface with several nudge services including a range of energy consumption, with two bounds; a higher level: the consumption as usual (CAU), and a target to reach: the goal. In the same time a genuine loyalty program called EcoTroks^{TM} was also developed. This paper explains how this electricity consumption range, from CAU to *the goal*, is computed and how the associated loyalty program seems to be an efficient manner to keep people involved in the program.

Introduction

The ongoing research on Smart Grid's deployment and applications [1, 2, 3] promotes the energy management in residential dwelling [4, 5, 6]. The future integration of smart metering needs to set new tools to inform and educate the final user to new consumption modes in the housing. Indeed, for many families, energy management is not a particular priority as the energy price is not high enough to be a significant part of the household expense.

It is still important to find a way of informing the final user so as to put them in a central place to be able to use all the potential of the smart grids. The *demand response* process that will be possible in the residential sector with the appropriate technologies will need the active participation of the final user. So how can we change the end user behavior to become active and reactive in his energy consumption?

It is the aim of the Grid-Teams' project supported by the program “agir ensemble pour l'énergie” of the regional authorities for south east of France (Région PACA) and the French agency for environment and energy management (ADEME) and coordinated by the company Gridpocket. The project involves the following companies: Planete Oui, WIT, the city of Cannes (in the south of France) and research laboratories (the Centre for Applied Mathematics of Mines ParisTech and the Sociological Centre of Telecom ParisTech). This project has developed a specific tool to assess the families' consumption and help them in the energy management of their housing. The originality of the project is to encourage the families in their way of having a better energy management by creating some social and cultural incentives. To verify the veracity of the methodology, the project has conducted experimentation on 40 families during one year in the city of Cannes [7].

We will present in the first part of this paper the methodology that has been employed to assess the housing and the family's energy behavior. In a second part we will present the tools that have been developed and deployed on the experimental panel. Then in the last part we will present some results obtained with some families.

Methodology

The project presented here aims at explaining the families the way of they use energy in their housing. As soon as they will understand where they can act to reduce their consumption, then they will be able to plan actions to reduce their consumption.

To achieve such an objective, we have to propose these families some tools to assess their consumption and other methodologies to make them active in the reduction of their consumption. To be able to show the users their consumption's level and to give them bounds adjusted to their particular case (an upper bound and a lower one), it is necessary to know details about three aspects:

The first one is **the structure of the housing**; the second one is **the appliances employed in this housing** and the third one is **the behavior of the family** living in this housing regarding energy uses. When these three topics will be identified, we will be able to propose them a kind of instrument panel that will show them in real time their consumption and the corresponding level regarding their specific bounds.

For these three levels of information we have to focus on, detailed inputs are very difficult to obtain without a completed study for each housing. The project proposes to elaborate a simplified model that can be representative of each housing without having resort to detailed analysis. To provide such a tool, we have analyzed a panel of 40 housings to validate our methodology.

Structure characterization

First of all we have realized a dynamic thermal simulation of the housing to determine its thermal performance and its sensitivity to its environment [8, 9]. The aim of this simulation is to determine some key parameters to elaborate some criteria that can be reused for similar buildings. For example, in a flat, the numbers of neighbors or the structure of the building is of a high importance to evaluate the bounds of the energy consumption.

Here is a scheme of the model for a flat that has been modeled with Comfie/Pleiade software.

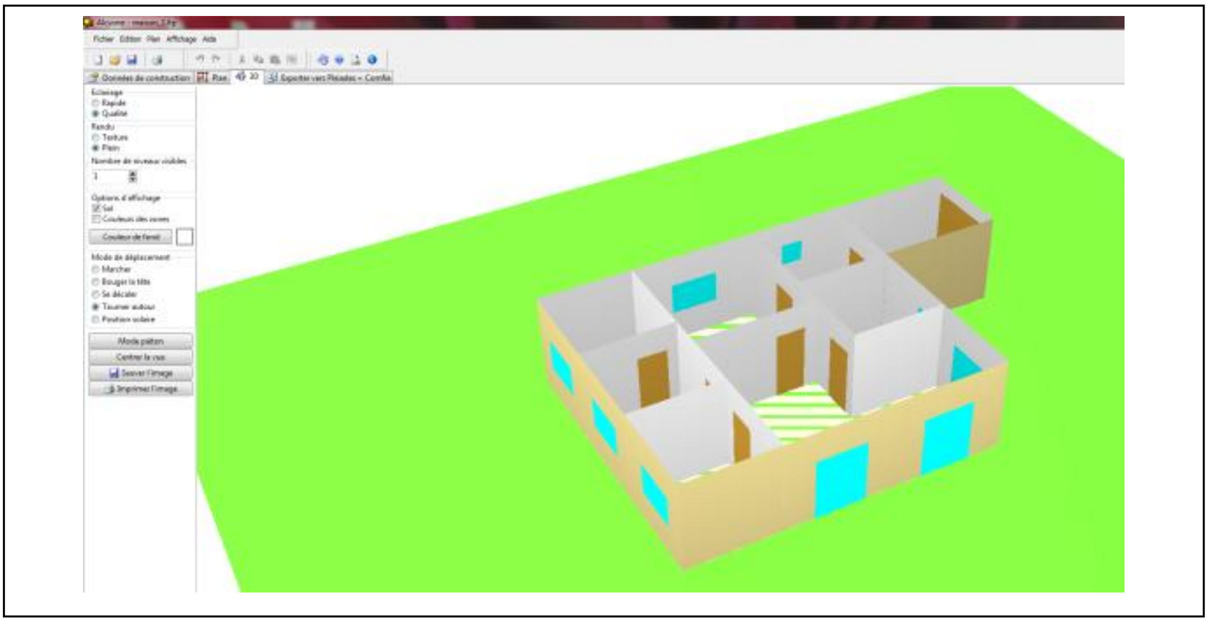

Figure 1 - Example of the housing representation in the dynamic thermal simulation tool.

With this simulation we obtain the need of the energy need of the building to maintain a given comfort temperature during an all year.

After that, the confrontation of these detailed simulations with a simplified thermal model for the building brings us to be able to identify the global thermal looses coefficient that can be identify to a category of building. This combination of the detailed way and a global way of calculus permits to elaborate some cursors to characterize similar buildings in the same range. The finality of this structure's building evaluation is to provide some cursors that can be adjusted with the results of a simplified survey.

Appliances characterization

The second phase is to inventory all the appliances in the housing and to assess the use of them by the families. It is difficult to quantify the reality of a specific use for an appliance. For example, how long do we use a kettle in a day? To achieve this inventory and the level of use of them, we have worked with the results of a European project (Remodece) [10, 11, 12] that has produced a big database of appliances load curves for several countries. Regarding the appliances, first of all different categories have been established to ensure a generalization of the methodology. Indeed, the numbers of appliances are too important and too diversified to have, for each family, and exhaustive count of them. And even it could have been possible, the quantification of their exact use is impossible to implement except with an energy metering for each of them that is not feasible. To compensate this lack of available information, a "brown" category including all appliances dealing with audio and video (TV, DVD player, video games, internet box…) has been created. A "white" category has also been created included all appliances we can find in the kitchen (Washing machine, oven, coffee machine…). The lightning, hot water, heating and cooling of the building are considered individually.

With these categories, two kinds of index have been determined. The first one is the level of equipment of the family. Based on a simplified survey regarding the kind and the number of appliances the family's got, the cursor can be move from a low equipped family to an over equipped family. The cursor will imply a level of power installed for appliance in the housing. The second one is also based on a simplified survey that evaluates the order of magnitude of the use of these appliances. This cursor can vary from a low use to an intensive use of these appliances. This level will determine a level of energy consumption in the housing. The combination of these two cursors gives a characterization of the family regarding their appliances uses in term of energy consumption and then it becomes possible to inform the family on its behavior.

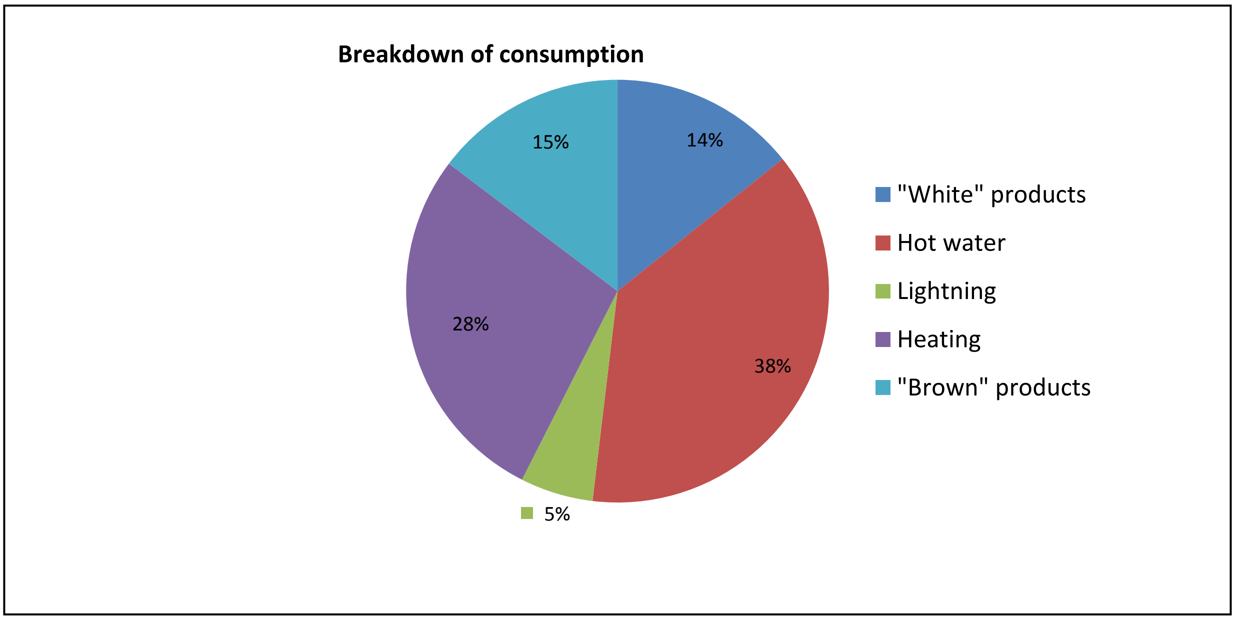

Figure 2 - Example of a breakdown of the consumption a of family provided bay our characterization

Behavior characterization

The last phase is to have an idea of the family behavior inside its housing. It is a very tricky task because this assessment can provide very significant differences in the results. To achieve such a goal, a sociologist team has realized detailed interview of the panel of families involved in the experiment. With these interviews, the sociologists have to identify the most pertinent characterization of a kind of family in term of its energy sensibility to be able to inform them about their uses and to orient them to a path of a more efficient way of their energy management [13, 14].

These interviews have to be match with their relative energy profiles (Building and appliances characterization) to provide an estimation of the differences we can observe between the theoretical energy needs regarding the structure of the housing and the real energy consumption realized. The second important point of this part of the analyses is to characterize the ability of the family to react to its own consumption and its capacity of reaction to these signals. The behavioral changes have to appear and also have to be sustained in a long term. To achieve with goal, the tools deployed in this project have to be well adapted for family that may not have any knowledge of energy topics. Some incentives have been included to strengthen such a goal. Indeed, one of the originality of this project is to add social incentive to the process of encouraging the families to a way of a better energy management of their housing. The goal is double; on the one hand is to encourage the family to make efforts on their energy consumption, on the other hand it is to develop some new social links as a consequence of their efforts. The incentive provides some useful gifts as bus ticket, low consumption light bulb, or social or cultural activities like concert places of tickets for local events.

The results of this behavior's characterizations have to be consolidate at the end of the project to assess its sustainability. The results of such a methodology can strengthen the effect of energy efficiency actions [15, 16].

Tool conception

To assess the characteristics of the buildings and to be able to provide the information in real time to the families, a smart meter has been installed in each housing of our panel. This smart meter is sending to a data center the power consumption of the housing each 50 watt modulation. These data provide to the system the detailed load curve of the family. Moreover, the temperature of the principal room of the housing is also sent to the data center. This temperature measure is very important to assess the comfort level and also give us precious information on the thermal behavior of the family. As the heating and cooling energy consumption can be the most important part in a building that do not correspond to the latest thermal regulation.

Regarding the results of the three characterizations describe previously, a web interface has been created to show the families their load curves and the bounds that correspond to their specific housing. A direct and secure connection for each family has been crated and they can interact by Email with a person that can answer to their interrogation. Moreover, the system can provide individually some advices after a rough analyze of their load curve to put them on the way of their energy management.

Web Interface development

The interface is the meeting point between technic and human. Therefore, it must be a good balance between information and usability, which means that the data should be bring to the user in the more easy to handle manner. This part explains the data path from the dwelling to the final user, from smart meter to Internet browser.

Data harvesting and storage

In France, the smart meter deployment is not completed yet; for the purpose of the Grid-Teams project we enjoy the help of the smart meter made by Wit, a French SME, targeted for industrial activity. This meter is able to measure, collect, store and send data for a huge list of commodity and time slice. On our experiment three commodities were monitored, Table 1, and took as input for both the thermal model and the final display.

Commodity	Unity	Monitor with	Send every...
Power	W	Amper clips after main electrical meter	time a trigger of 50 W is activated
Energy	Wh	Amper clips after main electrical meter	hour during the day two hours at night
Temperature	C°	Thermometer	hour time a trigger of 2° is activated

Table 1 - Commodities monitored in the Grid-Teams project

Three kinds of data sharing information on the three fields characterized earlier see infra p.2. Power and Energy spend were needed to level and understand the electricity consumption but also to assess user equipment rate and to profile usages. In the mean time the inside Temperature was useful to compute the stress on heating devices; to well understand this fight for heating we also collect external temperature to have an amount of degree to beat.

Once collected at the box level, data were sent via the general packet radio service (Gprs) protocol to the Wit datacenter, then forward to GridPocket Datacenter where data were pre-processed for the display on Web Interface. The architecture, Table 2, built on open source technologies helps the data consolidation and display.

Architecture layer	Technology
OS	Ubuntu
SGBDR	Postgresql 8.4.8
Application Server	NodeJs
Web Server	Nginx

Table 2 - Web Display architecture

Web Interface vs. In-home display

In the Grid-Teams project we choose the Web Application display instead of an In-home one because of the lighter development, the cheaper cost and the agility of the process. That means in a large-scale deployment to deal with the Web Access. By agility and large scale of features, we mean examples shown in the next paragraph.

Features

The design process involved final users in a co-conception process, to ease the service's acceptability by all users. There is two ways of displaying data in Grid-Teams, on one hand a simply informational way and on the other hand an augmented way, to nudge the energy efficiency. The second one involves some analyses and engines, when the challenges of the first stay in the best way to display the chart and plot to be understandable[1].

[1] Finding the good shapes and design for plot and graph are not as easy at it seems, these challenges need ergonomics and designer skills. Within this project, with a lack of support in this fields we exchange directly with the users.

Energy data

The way people consume energy could be display through different displays, from a gauge at a specific moment, Figure 3, to a time series with the choice of commodity to display, Figure 5, Figure 4.

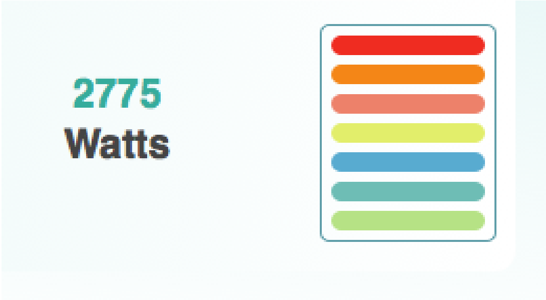

Figure 3 - Wattmeter

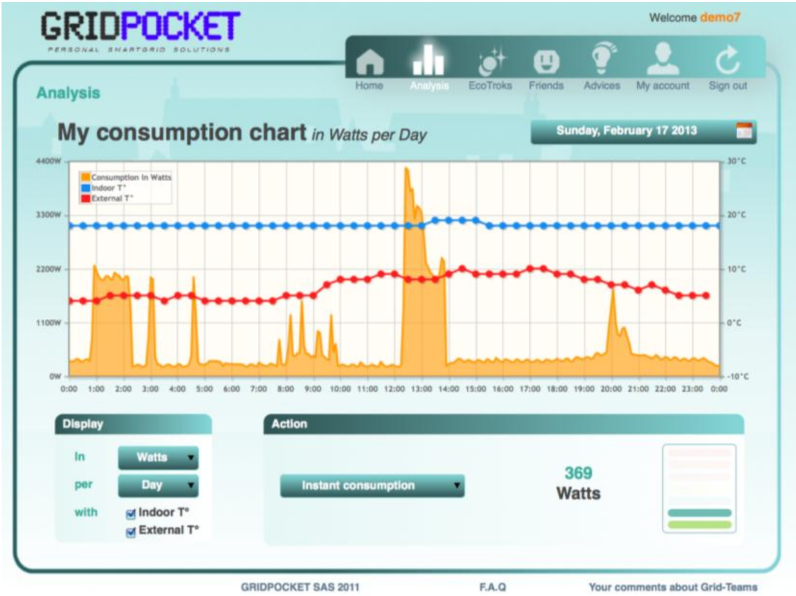

Figure 4 - Load Curve for user Demo 7 the 17th feb.

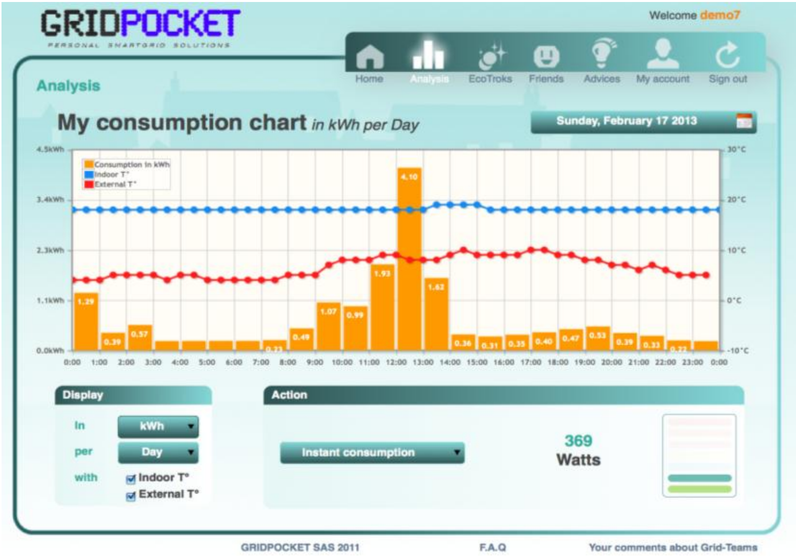

Figure 5 - Energy by hours within a day

Without help these information were already useful, but in some aspects quite difficult to handle and were not that easy to start switching for an energy efficient behavior. Other tools were offered to help the action to start.

Currency data

Speaking in technical terms, like the energy data above, can be sometimes hard to understand, so we decide to translate energy consumption to money.

Figure 6 - From energy to money

Scale and loyalty program

An important thing to do to motivate the participant and to keep him in the dynamic of the project is to show them bounds. The fact to show that you have to stay away from your upper bound and that you have a lower bound that is reachable is crucial. These bounds have been converted into currencies but are calculated with the thermal building knowledge, the appliances and behavior of the concerned candidate. Figure 7 show what the candidate can see on his interface.

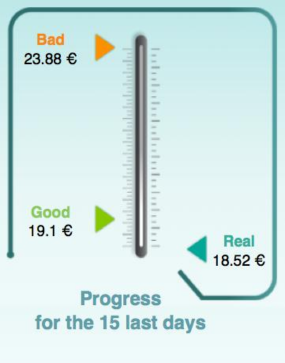

Figure 7 - Energy Scale

Showing bounds permit to assess the efforts that have been made, but for energy savings, due to relative low gains that can produce a real effort, a supplementary action has been integrate to the project. It is the reward mechanism that we have called EcoTroks TM. This reward is calculated regarding the level of effort that can be shown on the previous figure. If the candidate has reduced its consumption during the previous week, it earns some EcoTroks. The calculus of the level of EcoTroks earned by the candidates regarding their specific case is not explained in the present paper. With their EcoTroks, the families can choose rewards on a dedicated WebSite. When it is validated, they can go to the town hall of the city of Cannes to take them. It is the city of Cannes that has provided the rewards for the project. The figure below represents the screen shot of the EcoTroks Shop.

Figure 8 - The program's shop

Experimentation and results

Enrolment of the candidates

The project consist in an experiment conducted on a reduce sample to validate the methodology describe in the previous section. The first step was to proceed to the selection of a representative panel of family that corresponds to the different constraints we have decided previously. To be able to manage such experimentation we decide to choose specific housings principally renters with electrical heaters. We also decide to have various types of families (singles, families with children …).

The selection process was a project's milestone; the enrolment goes through a public advertisement and with the help of a city database of green association[2]. The sociologists have provided some questionnaires to manage the final choice for the experimentation. A panel of 30 families has been chosen at the beginning of the study and at the end of the project, 20 families have conducted the complete experiment. Some of them have given up because of a lack of time or because they have changed their housing. Several causes have been identified but the majority hasn't given up due to their lack of interest in the project.

Smart metering

For each family a smart meter design, built by WIT was installed. This smart meter was programmed to send to the data center of the project every change in the power level as it exceeds 50 watts (See previous part above). The project will assess the capacities of the use of such devices in helping distribution grid operator (DGO) to have a better understanding of final user's behavior. In our experiment, this metering and the frequency of data transmission have a key role in the analysis we can produce and for the representation we want to show to the final user.

Sociological questionnaire survey

For each family that has been enrolled in the experiment, a Sociologist has met the family and several individual and group meetings have been made to explain the purpose of the project and to assess the characteristics of the candidates in term of their level in the energy management feeling at the beginning of the project. Each interview of the candidate has been recorded (audio and video) with the authorization of the participant and the interviews have been transcribed and analyzed. The procedure of explanation in several stages is very important in the acceptance process of the project. This kind of information is essential to be able to establish the progress of the candidates during the project and their ability to continue in the same way.

Results

From a one year experiment a lot of feedbacks were significant for all the partners from the smart grid deployment point of view, technical issues, marketing tools to be improve, thermal model

One of the main results is the involvement within the loyalty program; orders were sent during all the program time.

From energy efficiency perspectives the results need to be improved and tested in a larger scale, but first analyze brings a reduction close to 10 % from an assumed consumption as usual. The loyalty program EcoTroks played a significant role in this dynamics. The two figures below, show two different situation, Figure 9 shows an user earning and spending EcoTroks (TK) in the Grid-Teams shop, we can see a consumption stick to the target while an other user, who didn't care about the loyalty program, who was more erratic (and sometimes even more efficient) and finally less efficient in average.

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[2] UN's Action 21 for the twenty-first century was implemented by french government in an "Agenda 21" plan where cities and local government were able to labelise associations and other green actions groups.

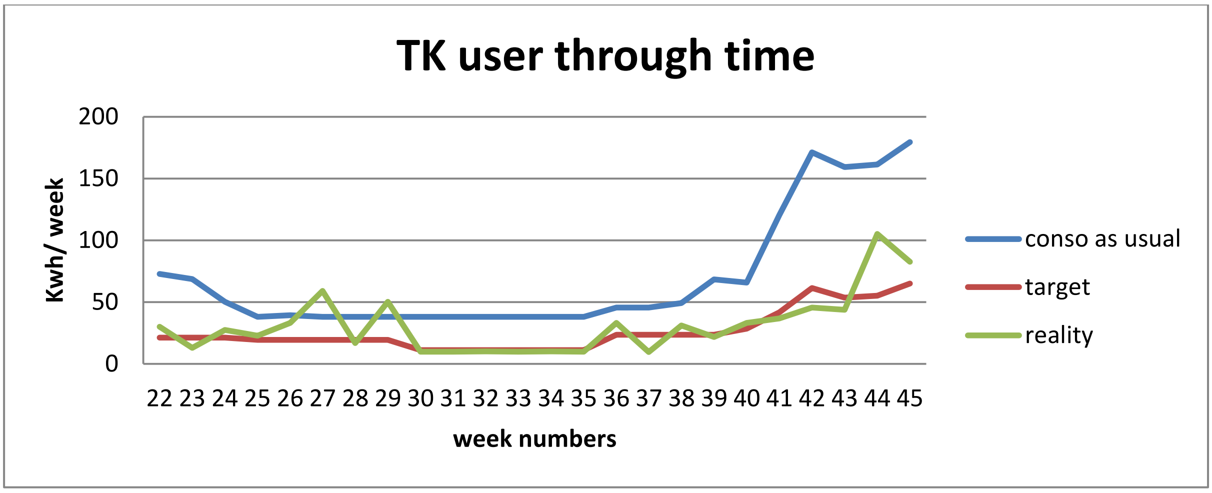

Figure 9 - User with TK gain, with a real consumption close to the targeted one

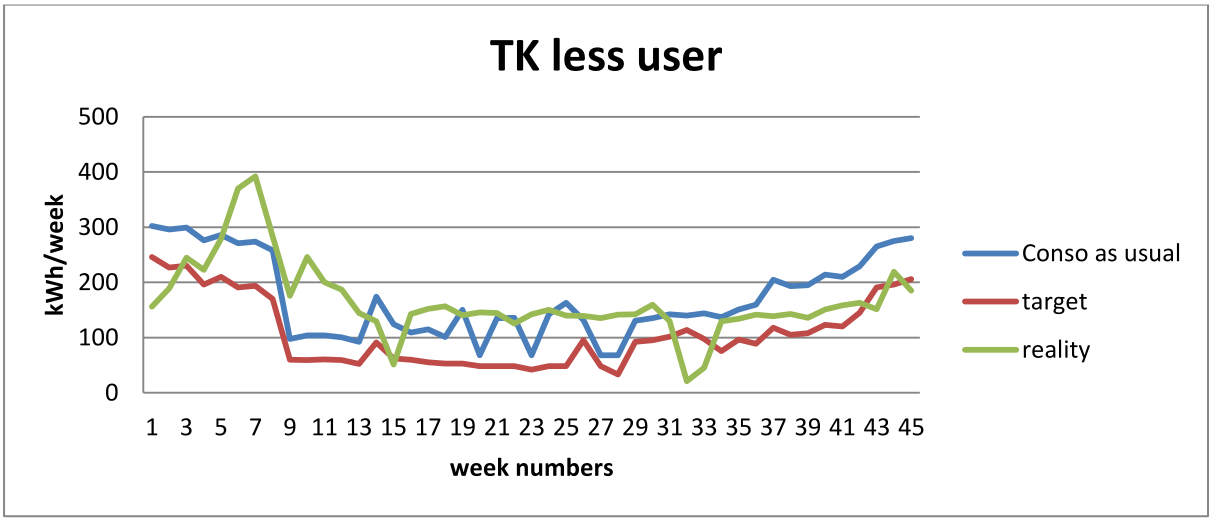

Figure 10 - User without TK, no clear path followed

Conclusion

The Grid-Teams project was an opportunity to test the potential of a smart meter for residential users in a way of energy reduction. The project shows that with a fine data collection, a fine analysis with a sociologist team, families can be involved in an energy management process. The methodology shows that we need some preliminary questionnaires (for the building part and for the inhabitant part) and a quick sample for the electricity consumption to be pertinent in our assessment of the family behavior. The results for the families are really encouraging. They validate the concept of the kind of information we have to provide to the families by our web interface to make them involved in a way of a sustainable reduction of their use of energy.

This is a first step towards robust tools that could be deployed at a large scale as soon as the smart meters will be available. A following project is forecast in this way to test the part that we couldn't test during this project. It is the social implication of the family regarding other similar families. A specific web interface was studied to imply a group of families and to put some competitions between candidates through the social networks to encourage them to reinforce their effort with the comparison they would make between each other.

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Monitoring and Evaluation of Green Public Procurement Programs

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Abstract

Effective procurement policies can help governments save considerable amounts of money while also reducing energy consumption. Additionally, private sector companies which purchase large numbers of energy-consuming devices can benefit from procurement policies that minimize life-cycle energy costs. Both public and private procurement programs offer opportunities to generate market-transforming demand for energy efficient appliances and lighting fixtures.

In recent years, several governments have implemented policies to procure energy efficient products and services. When deploying these policies, efforts have focused on developing resources for implementation (guidelines, energy efficiency specifications for tenders, life cycle costing tools, training, etc.) rather than defining monitoring systems to track progress against the set objectives. Implementation resources are necessary to make effective policies; however, developing Monitoring and Evaluation (M&E) mechanisms are critical to ensure that the policies are effective.

The purpose of this article is to provide policy makers and procurement officials with a preliminary map of existing approaches and key components to monitor Energy Efficient Procurement (EEP) programs in order to contribute to the improvement of their own systems.

Case studies are used throughout the paper to illustrate promising approaches to improve the M&E of EEP programs, from the definition of the system or data collection to complementary instruments to improve both the monitoring response and program results.

1. Introduction

Public procurement is the process whereby government organisations acquire the goods, constructions, and services (referred to hereafter only as “products”) required to operate and perform all necessary functions. By introducing environmental considerations into procurement processes and requirements – that is, by implementing Green Public Procurement (GPP) – the public sector reduces the environmental impacts of its operations, improves efficiency, and can reduce expenditures by reducing purchase needs and minimizing life-cycle costs. GPP requirements encompass a large number of environmental considerations, and usually include energy efficiency as this contributes to reduced energy consumption and costs by organisations.

In OECD countries government procurement represents approximately 18% of GDP [1] and up to 30% of GDP in developing countries [2]. Given the market share that the public sector represents, public procurement can transform the market for green solutions, eco-innovations and new, environmentally conscious business models. Therefore, the public sector is increasingly including procurement as a policy instrument to achieve the objectives set in a wide range of environmental and economic development policies.

To support practitioners implementing green and/or energy efficient procurement, efforts have focused on providing resources for implementation (including guidelines, environmental specifications for tenders with information on verification documents, lifecycle costing tools, best practices recommendations, or training) while little or no attention has been given to establishing mechanisms or systems to monitor and evaluate policy implementation and results.

When monitoring EEP/GPP programs, organisations track the implementation of the actions and measures taken as part of the program. With this information, policymakers can evaluate progress against policy objectives, and identify areas that need improvement, which will help in the development of supportive measures to improve efficiency and effectiveness in policy deployment. Furthermore, making results available both internally and externally demonstrates political commitment, enhances transparency, legitimizes the promotion of sustainable consumption and production by other sectors of society, and promotes policy embedment throughout the organization by keeping each agency accountable. As is often the case, accountability increases policy compliance. The type of M&E system that an organisation will choose to put in place will depend primarily on the objectives and actions set at the policy level, as the system will serve to track and assess progress in relation to them.

2. EEP at Policy Level

2.1. Policies Including EEP Requirements

Public authorities around the world are adopting policies that encourage or require the acquisition of energy efficient products by the public organisations within their jurisdiction [3]. The type of policies range from normative regulations and laws to general guidelines or recommendations, and their focus can vary from a specific energy efficient product, to general green procurement, climate protection, green growth or sustainable development as a whole. Table 1 presents the main type of policies where EEP commitments are included, with some examples from countries with different levels of economic development.

Table 1. Type of Policies Including EPP/GPP Requirements

Policy scope	Examples
Product-specific policies	Examples from the European Union include: - Regulation (EC) No 106/2008 of 15 January 2008 on a Community Energy-efficiency Labelling Programme for Office Equipment. - Directive 2009/33/EC of 23 April 2009 on the promotion of clean and energy efficient road transport vehicles. - Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings.
Energy efficient procurement policies	- China Circular of 17 December 2004 on the Implementation of Government Procurement of Energy-saving Products and Circular of 30 July 2007 on Establishing a Mandatory Government Procurement Scheme of Energy-saving Products. - Japan Green Contract Law (Law No. 56 of 2007) Concerning the Promotion of Contracts Considering Reduction of Emissions of Greenhouse Gases and Others by the State and Other Entities.
Overarching green procurement strategies	- Canada Federal Government Policy on Green Procurement. - Brazil Regulation nº1 of 19 January 2010, on environmental sustainability criteria in the procurement of goods, services and works of the Federal Public Administration and related agencies. - Spain Order PRE/116/2008 of 21 January 2008 publishing the approval of the Plan on Green Public Procurement of the Central Government and Related Agencies.

Energy/ Environmental operations policies	- United States Executive Order 13514 of 5 October 2009 - Federal Leadership in Environmental, Energy and Economic Performance. - United Kingdom Greening Government Commitments: Operations and Procurement (February 2011). - France Circular of 3 December 2008 concerning the exemplarity of the State in respect of sustainable development in the operation of its services and institutions.
Environment protection policies (such as climate protection strategies, sustainable development strategies, etc.)	- Mexico City Climate Action Program 2008-2012. - South Africa Notice 908 of 2009, National Energy Efficiency Strategy of the Republic. - Colombia National Development Plan 2010-2014: Prosperity for all.
Green growth policies	- United States Farm Security and Rural Investment Act of 2002 (FSRIA) and Resource Conservation and Recovery Act (RCRA). - European Union Lead Market Initiative.

Source: Ecoinstitut.

2.2. The Effect of Policy Objectives in the Definition of M&E Systems

The objectives and targets of the policies that include EEP requirements are diverse. For example, in its Communication Green Public Procurement for a Better Environment, the EC proposed that by 2010 50% of all tendering procedures should be green [4]. In Japan, the policy concerning the Promotion of Contracts Considering Reduction of Emissions of Greenhouse Gases and Others by the State and Other Entities, also known as Green Contract Law, sets the objective to reduce direct and indirect GHG emissions by 8% from 2010 to 2012 using the 2001 level as a benchmark through contracts related to the supply of electricity, the procurement and leasing of vehicles, the procurement of ships, the construction and/or renovation of buildings, and contracting Energy Service Companies [5]. In Spain, the GPP Plan of the Spanish Central Government sets different objectives depending on the actions. Thus, the plan includes an objective of energy saving of up to 9% by 2010 and 20% by 2016 in buildings; a reduction of 20% in fossil fuel consumption and an increase in the consumption of biofuels to up to 38% in transportation; and for IT equipment, 100% of all new computers, screens and imaging equipment must comply with the energy consumption limits defined in the Energy Star standard [6]. Mexico City's 2008-2012 Climate Action Program set specific annual CO_2-equivalent reduction targets for a variety of energy efficient measures in public buildings, transport, and other areas [7].

The different objectives set at the policy level can be classified into four main goals related to procurement that can be present either individually or in combination:

1. To transform the market for energy efficient products
2. To achieve greenhouse gas (GHG) mitigation and reduce other environmental impacts
3. To embed EEP/GPP in the organisations' operations and procedures
4. To increase actual procurement of environmentally preferable products and services

The first two, *final goals,* justify the inclusion of EEP requirements. The other two, more *practical goals,* determine how to reach those final goals.

As the objectives of each policy might be different, the design of the M&E system will vary, as it has to be in line and able to track and assess progress in the achievement of the set goals and commitments.

3. Monitoring EEP Requirements

As listed above, one of the principal reasons for introducing EEP requirements in policies is to serve as a catalyst for the market penetration of green products and services. As such, an approach to evaluating the success of EEP commitments could be to assess to what extent EEP has contributed to an increase in the market share of more energy efficient products. However, this approach has rarely been followed, this may be due to the fact that market transformation is used as a motive or justification but no targets are set to monitor against. Also, the public sector is not the only player nor is public procurement the only instrument influencing market changes. Instruments such as taxes, subsidies, regulations, and demand from the private sector and consumers can have a more significant impact, making it difficult to measure the effect of EEP in market changes. Furthermore, such studies might have a negative cost-benefit balance, as the resources required to conduct the research does not justify the benefits yielded. These studies analyze the market and may provide limited useful information for better EEP embedment. We should not forget that monitoring is not only used to evaluate policy compliance and results/impact, but also to hold agencies accountable for better implementation and to identify areas for improvement and this information cannot be obtained through market studies.

In comparison to market transformation monitoring, assessing EEP embedment in operations is a much more straightforward process. In all the cases analyzed, the M&E systems to track and assess compliance are based on surveys, which for the most part require little or no data digging and gather qualitative information, making them easy to complete. One weakness of surveys is that the results are not always precise and may represent only the opinion or perception of people who complete them. This is especially critical when results are compiled to reflect the entire organization, because procurement is decentralized and may be implemented differently in each department. To accurately evaluate the extent to which EEP is actually conducted in procurement processes a more objective and quantitative analysis of procurement of energy efficient products is recommended.

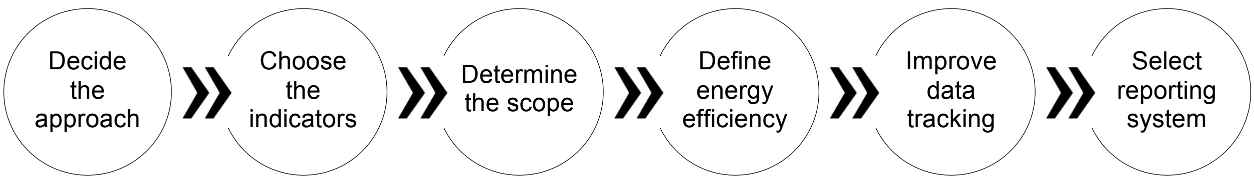
Therefore, this paper focuses on the two M&E approaches to measure EEP implementation and results that have received the most interest from government agencies: 1) the monitoring of the procurement level of energy efficient products and 2) the assessment of the environmental relief achieved through EEP.

3.1. Monitoring the Procurement of Energy Efficient Products

In order to measure actual EEP implementation, many organizations have developed or are developing M&E systems to quantify how many of the products they buy/contract or the tenders they publish include or comply with energy efficient or other environmental criteria. In fact, this is the approach where more examples and experiences from public authorities exist.

In order to set up such a system, different elements have to be considered, which are summarized in Figure 1 and discussed below.

Figure 1. Steps to Design an M&E system for the Procurement of Energy Efficient Products



Source: Ecoinstitut.

3.1.1. Decide the Approach

The first decision to be made is whether to monitor tenders or actual purchases. This decision can be made at the policy level, or may be defined later if objectives are not specified in such detail in the policy. In the second case, it is advisable to first analyse existing data tracking systems (see section 3.1.5) before deciding on the approach.

The main advantage of *monitoring tenders* is that they can be tracked more rapidly than product purchases, as all the information is found in the tender itself and does not require data input from different people or from suppliers.

The disadvantages are that when monitoring tenders, direct purchases are frequently, if not always, excluded from the scope of the monitoring, losing what might be an important portion of overall public procurement. Special attention must also be paid to framework agreements; they might approve several products and/or companies, but the resulting secondary contracts might not qualify as energy efficient. Furthermore, monitoring tenders does not show, in general, the actual result of the process and what is purchased or contracted in the end. Thus, a tender counted as "greened" might not yield the acquisition of an energy efficient product, unless only tenders with compulsory environmental criteria qualify as such. Nevertheless, it is often argued that for public procurement to create a market pulling effect for energy efficient and green products, organizations have to clearly signal to suppliers their green purchasing preferences. Public administrations do this through their tender documents and purchase orders, which capture their organizations' purchasing requirements. Therefore, to evaluate the impact, it would not be necessary to monitor what is actually procured, but the degree to which energy efficiency criteria are included in tender documents.

The advantage of *monitoring acquisition* of energy efficient products is that this shows not just intentions, as could be the case when monitoring tenders, but rather actual purchases. This type of monitoring tends to cover all kinds of purchases—both from contracts and direct purchases—and facilitates the evaluation of environmental relief achieved with EEP (see section 3.2).

However, tracking green product acquisition is less straightforward than tracking tenders. Financial systems and budgets are normally aggregated and coded at a higher level than product procurement, so certain products might not be directly identifiable in existing systems unless they are set up to track information at a product level. Additionally, products used within service contracts cannot be tracked using the organizations' systems, but require input and reporting from the service providers. That can be an obstacle to tracking given the tendency to outsource services, and to change acquisition models from procurement of products to services. Also, purchases occur more frequently than tenders, increasing the number of transactions to be monitored. Such transactions are normally carried out by a larger number of people, which implies the involvement of more staff in tracking green expenditures, increasing the possibility of data errors.

Therefore, tracking tenders is easier than tracking purchases unless products are purchased through procurement platforms (stores or catalogues), which allow direct and automatic tracking.

3.1.2. Choose the Indicators

Secondly, organisations must define the Key Performance Indicators (KPIs) to express and evaluate results. According to the case studies analyzed:

- When monitoring tenders, the indicators most commonly used are the total amount and the percentage of tenders (both in number and in economic terms) that are green in relation to the total amount within a given reporting period.
- When monitoring the acquisition of products, the level of EEP is calculated using the total amount and the percentage of energy efficient products purchased in terms of expenditure and, to a lesser extent, in units in relation to the total purchased during the reporting period. This second indicator is relevant to estimate the environmental benefits of EEP based on products, as normally environmental factors for transforming green purchases into environmental benefits use number of units purchased rather than economic ones (see Section 3.2).

3.1.3. Determine the Scope

Thirdly, the product groups that will be monitored must be identified. Public administrations buy or contract many different types of energy-consuming products (IT equipment, vehicles and transport services, traffic and street lighting systems, building heating and cooling systems, medical appliances, vending machines and kitchen appliances, etc.). Organizations might focus on all of them, but normally a group of priority products is chosen. Examples of criteria considered when selecting product groups to monitor include: 1) prior selection at policy level; 2) the existence of standardized EEP criteria at the regional, national, or municipal level; 3) the availability of energy efficiency standards and/or labels (if no standards exist, it is very difficult to implement EEP); or 4) the significance in terms of expenditure and/or ubiquity within the organizations being monitored.

3.1.4. Define what Qualifies as Energy Efficient

For a tender or purchase to be considered energy efficient, it is necessary to first define the parameters by which it will qualify as such. This is normally based on standardized labels or EEP/GPP criteria implemented at the regional, national, or local levels.

<u>Case 1. Chinese Government Definition of Energy Efficient</u>

In 2004, the Ministry of Finance and the National Development and Reform Commission promulgated an EEP policy, the “Implementation Guidelines for Government Procurement of Energy-saving Products”, which required public agencies to give preference to energy efficient products when procuring (becoming mandatory for certain product groups from 2007). Energy efficient products are defined as those that have been awarded the Energy Conservation Certification of the Chinese Government and are included in the Government Procurement List on Energy Conservation Products [8]. The definition refers to the existing National energy label.

<u>Case 2. Definition of Energy Efficient in the Pilot M&E Methodology of the European Union</u>

In 2008, the European Commission (EC) contracted the development and testing of a methodology to monitor the implementation of GPP in the European Union (EU). Contractors used the existing EC GPP standard criteria developed the previous year to define what qualified as energy efficient. IT equipment had to comply with the energy consumption thresholds defined in the Energy Star standard [9], thus using a standard as reference. For passenger cars and light duty vehicles, there is not yet an energy efficiency label at the EU level (unlike other energy-consuming products such as electrical appliances/white goods or tires), but all vehicles are sold with a compulsory label that informs consumers of the average CO_2 emissions per kilometre of the vehicle. Therefore, the M&E methodology used this label and the GPP criteria to qualify vehicles as “green” if the CO_2 emissions of awarded vehicles were below the maximum threshold defined for the vehicle’s category. [7]. In this case, the EC GPP criteria in combination with the compulsory label were used as reference to define “green”.

3.1.5. Select, adapt or set data tracking systems

One of the difficulties of monitoring EEP in terms of expenditure in green products and services or incorporation of environmental criteria in tender documents is the lack of integration of EEP tracking requirements within existing procurement and/or financial procedures and tools. Because of this, data is not systematically registered and annual tracking of EEP is extremely time-consuming, especially when EEP covers a wide variety of products and services and there is little centralization. Additional difficulties might arise if EEP is monitored as part of GPP policies and the criteria used to define “green products” demands compliance with multiple specifications.

Listed below are methods that may be used to track the purchase of energy efficient products or data on product use in service contracts.

- *Adapt internal financial systems to track expenditure at product level*. This approach might also require adaptation to track the number of units purchased as organizations typically only record expenditures. However, these systems don't allow the tracking of products used within service contracts and require input by many different people, increasing the risk of errors.

- *Insert reporting requirements in tender and/or contract language.* This approach makes providers accountable for tracking green product sales to public authorities and is crucial for tracking products used within services. If this method is used, it is very important to clearly define: 1) what qualifies as green, as vendors might erroneously describe items as green, and 2) what information is needed to integrate data from other providers, compare results between units or agencies, and/or calculate environmental benefits - thus organisations have to develop data reporting standards. Some downsides are that it is difficult to verify data accuracy and information gathering can be time consuming, requiring tight contract management by the administration to ensure that contractors deliver reports.

- *Use or develop electronic catalogues for centrally purchased items*. These systems make information easily available internally, provide accurate data on energy efficient product purchases (for both expenditures and physical units), and allow central analysis without requiring reporting by each organization or department. The downside is that this method is only useful for a limited number of products, as most purchases are not centralized nor are all of them suitable for an e-catalogue, and cannot yield data on products used within service contracts.

The following strategies may be used to track data more efficiently when the monitoring approach is based on tenders:

- *Insert a section in the tender documents that clearly identifies any applicable energy efficiency criteria*. This method makes it easier for departments or organisations to identify green tenders, but it still requires manual analysis and reporting. This may be done for example with: 1) a simple checkbox to indicate whether green criteria have been introduced in the tender; 2) a table for purchasers to indicate where in the tender EEP criteria have been introduced (technical specifications, award criteria, etc.); 3) a list that indicates if criteria for designated products have been introduced; or 4) a table to indicate if national or local standard green criteria have been introduced (fully vs. partially, core vs. comprehensive, mandatory vs. best practice).

- *Request procurers to complete a form when submitting a bid, awarding a contract, and/or completing a project.* The form can summarize the energy efficiency or green criteria introduced in the tender or complied with by the awarded offer, depending on how the indicator has been defined.

- *Adapt information fields if using an electronic tender publishing platform to track relevant information required for the M&E system.* The benefits of such systems are that they allow automatic data analysis, process larger amounts of information quickly, and minimize bias. However, if not properly programmed they might leave out certain energy efficient tenders, and using such automated systems might limit the awareness raised within the organization of the M&E process as no input is required from them.

Therefore, when quantitatively monitoring the level of green procurement, M&E systems should use data sources that are directly available and require the input of the least number of people in order to minimize errors, eliminate bias, and reduce the time required for M&E from the organisation as a whole. Measures that require adapting financial platforms, electronic catalogues, electronic tendering platforms, or any other procurement management software that can facilitate tracking green tenders or expenditures on green products requires an initial investment, but will save resources that would otherwise be required to collect data.

Some cases of administrations that have applied some of the solutions presented are described below.

Case 3. Tracking Green Purchases via the Finance System in Cardinia Shire Council (Australia) [10]

Cardinia Shire Council, a public authority in the State of Victoria (Australia), participates in the State's EcoBuy Program and is committed to buy green products and report progress annually. To do so, the Council has set up mandatory fields in its financial software that procurers fill in to accurately and consistently capture expenditures under various green categories. To ensure appropriate data recording, measuring, and tracking, green procurement has also been integrated into the finance system's procedures and training.

Case 4. Tenders Language for Procurement Tracking by Suppliers in King County (US) [11]

According to the guidelines for procuring environmentally preferable computers by King County, staff are required to include specific language in its call for tenders requiring suppliers to track and report green sales. Two options are provided. The first requires contractors to provide quarterly reports quantifying the EPEAT registered and unregistered products purchased under the contract in a format acceptable to King County. The second option includes a matrix that vendors have to use to report sales (see Figure 2).

Figure 2. Matrix for vendors to report green sales

	Unregistered		EPEAT Bronze		EPEAT Silver		EPEAT Gold		Total	
	No. units	$ spent	No. units	$ spent	No. units	$ spent	No. units	$ spent	No. units	$ spent
Desktops										
Laptops										
Monitors (LCD)										
Monitors (CRT)										
Total										

Source: Environmental Purchasing Program (2012). Environmentally Preferable Computers. King County.

Case 5. Tracking Sustainable Tenders in Chile Through an E-tendering Platform

The public sector in Chile uses two centralized electronic platforms for its purchasing activities. The national tendering platform, *Mercado Público*, centralizes the call for tenders of goods and services from most public agencies in the country (excluding public companies). The online store, *ChileCompra Express*, is used by public authorities to buy products centrally procured through Framework contracts by the Directorate of Public Procurement of the Ministry of Finance (known as *ChileCompra*).

When tendering through *Mercado Público*, public authorities not only upload their tender documents and publicize them, but also fill in several online forms that correspond approximately to the administrative tendering document. In these forms, procurers have to specify, among other details, the selection criteria for companies to be able to participate, administrative information about the tender (duration, guarantees, insurances, etc.), and the award criteria. Procurers can specify different award criteria from a list of categories, including Energy Efficiency and Environmental Impact. This information is registered in the platform database, making it easy to identify tenders that include energy efficiency or other environmental specifications as award criteria. The limitation of the system is that it excludes tenders conducted by public companies and it doesn't allow tracking of tenders that include compulsory energy efficiency criteria, as they are not registered in the platform database (the technical tender is uploaded as a document, preventing automatic search for environmental requirements).

For purchases conducted via *ChileCompra Express*, the environmental characteristics of awarded products are displayed in the online store as an output of the platform database, making it possible not only to quantify the tenders that included sustainability award criteria, but also tenders that resulted in the selection of more sustainable alternatives.

As the monitoring system is designed to use the parameters and variables registered in the e-procurement platform (in the form of SQL databases), the sustainable procurement indicator is very easy to obtain and therefore to monitor. Through standardized queries to the e-platform database, *ChileCompra* monitors the evolution of the percentage of sustainable procurement each month at the internal level, without requiring input from the organisations tendering through the platforms.

Case 6. Tracking green tenders in Malta [12 and 13]

Since 2012, procurers in the Government of Malta have been required to include GPP criteria set by the government in the tender documents for certain prioritized product groups. To monitor compliance, all calls for tenders must be supported by a form (Tender Originators Form), which was revised to include data on the application of GPP along with information on the tender (promoter, estimated value, lots, etc.). Procurers must submit a scanned signed copy of this form to the Office of the Prime Minister by e-mail to track and verify compliance.

3.1.6. Establish the Data Reporting System

After tracking the relevant data, information has to be reported to the organisation or department in charge of the overall monitoring for evaluation. As presented in the previous section (3.1.5), each department or organization may track and/or gather information from different data sources. For example, some data can be accessed directly by the "monitoring" agency or a central body reporting for all the organisations subject to the monitoring, while other data collection requires compilation by each department or organization.

Reporting data from procurement or tenders via a survey can be time consuming if too much information is required and no automatic system (not even at department level) exists, reducing the response rate. Moreover, results are rarely verified unless a small amount of data is required, and departments or organizations with low performance might not respond. However, the request can raise awareness and promote EEP implementation in the future. If all information is processed automatically and no benchmarking, training, or communication efforts are in place, departments or agencies may not be aware that EEP requirements exist and have no incentive or knowledge to implement EEP.

If data is centrally available, EEP evaluation can be conducted directly by the "monitoring" agency, reducing the monitoring time as little or no waiting time is required as compared to surveys. A central data source also makes it possible to analyze results from organizations with varying levels of performance. Thus data and results are more reliable and comprehensive than those obtained through a questionnaire/survey.

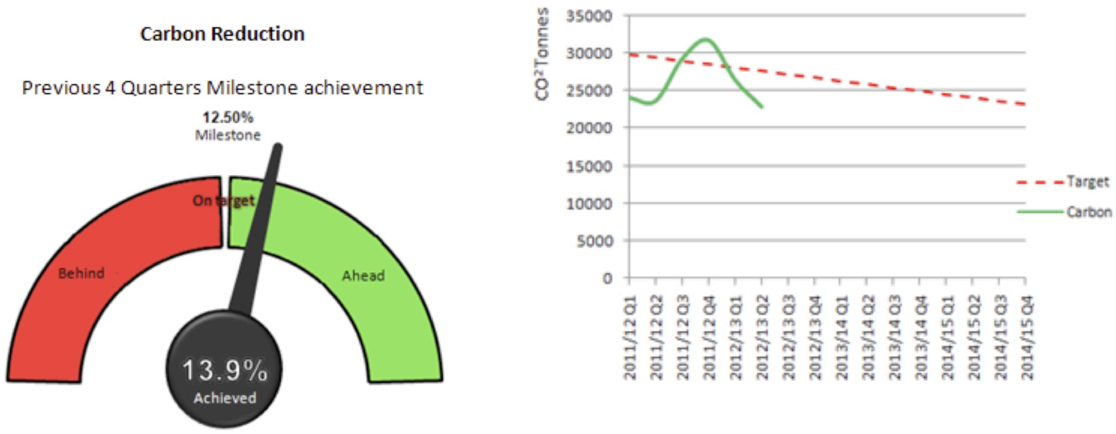
Whenever possible data reporting systems should: 1) be integrated with other reporting tools to simplify procedures; 2) be standardized to allow comparison among organisations; 3) be designed to require information in the same format as organisations gather it to avoid confusion; 4) be in an electronic format to facilitate data aggregation by the "monitoring" agency; and 5) be able to provide instant feedback on performance and progress to the organisations.

Case 7. Reporting Mechanism for GPP Monitoring in the United Kingdom (UK)

In 2006, the UK Government approved the Framework for Sustainable Operations on the Government Estate (SOGE) and the Sustainable Procurement Action Plan for the public sector as a whole. As the SOGE is the Central Government's umbrella for sustainable operations, it was agreed to integrate all elements of government sustainable operations, including those from the Sustainable Procurement Action Plan, into the SOGE monitoring and reporting system. The reporting mechanism was through an on-line questionnaire that gathered performance data reported by departments. Each department had its own system to collect and process the required data, but all of them input data in a standardized manner to allow comparison and benchmarking among departments. Until 2008 the questionnaire was a stand-alone tool, but from the fiscal year 2008–09 until the end of the SOGE reporting process in 2010–11 the questionnaire was integrated with the e-PIMS platform, an existing central government property database used to collect building-level data for other SOGE targets.

In 2011, the SOGE framework was replaced by the Greening Government Operations and Procurement Commitments (GGC) and the reporting system changed. The new system uses a spreadsheet as a template. One advantage of this method is that the spreadsheet automatically calculates and graphically presents each organization's performance against baseline data to show progress towards achieving the targets and forecast the evolution to the GGC deadline in 2014/15.

Figure 3. Defra's GGC Carbon Dashboard and Carbon Chart



Source: Department for Environment, Food and Rural Affairs. Greening Government Commitments: Defra's Performance. 2012/13 & Baseline. December 2012.

3.2. Monitoring Environmental Relief

Despite the fact that EEP is promoted as a means to reduce the environmental impacts of an organisations' activities and processes, very few of the EEP or larger GPP programs analyzed actually monitor the environmental relief obtained through the procurement of energy efficient or further green products. However, its calculation is more frequent when monitoring "green-the-government" or climate protection policies that include EEP requirements, as most of them set specific environmental relief objectives.

One of the main differences between general GPP and EEP is that purchasing energy efficient products can directly impact an organisation's environmental performance. The impacts of many green products (e.g. products with a high percentage of recycled content, bio-based, or free from certain hazardous substances) occur during the production phase and if they do occur during use by the administration, they don't have a direct impact on organisations' environmental parameters that can be monitored to evaluate environmental results. Energy efficient products influence the organisation's energy consumption, which is a measurable parameter. Therefore, environmental relief achieved through EEP can be measured or calculated by 1) the environmental characteristics of the products purchased or used in services and constructions and 2) on the energy performance of the products, constructions and services during its use phase, that is, while they are used by the organisation.

To evaluate results, the KPIs for EEP programs are quite straightforward and in line with other energy-related policies, namely energy consumption and GHG emissions (expressed frequently as CO_2-equivalent).

Given that this kind of monitoring tracks or estimates energy consumption, and information on product costs are also available, cost savings achieved with EEP can also be used as KPIs to support EEP in regions or organisations where costs of green products are often highlighted as an obstacle to GPP implementation.

3.2.1. Estimates Based on Products Purchased

When the environmental benefits are calculated based on the purchase of energy efficient products, the resulting figures are only estimates that can either over- or underestimate final performance. Furthermore, impact analysis generally focuses on the impacts during the use phase linked to energy consumption and is therefore expressed as a reduction in energy consumption or GHG emissions.

For such calculations, the first data points to gather are the number of products purchased or used. Data will have to be reported or adjusted to be in units that are consistent with the consumption units (see below). M&E system designers should take into account that sometimes only expenditures are recorded, thus requiring additional information can present a challenge for those that collect data.

Secondly, the environmental characteristics of the products, namely energy consumption per unit and energy source (electricity, gas, diesel, biomass, etc.), have to be registered. These characteristics can be either of the product – direct evaluation – or of an agreed proxy – proxy evaluation. In the first case, the exact energy consumption in each operating mode of the items purchased in a contract has to be registered. In the proxy evaluation, a reference energy consumption value is selected as proxy and applied to all products. For example, if televisions rated class-A according to the national energy label are purchased, reduction in energy consumption can be calculated using the exact energy consumption of each TV (direct evaluation) or using the minimum consumption for class-A as a proxy. While direct evaluation of the estimated environmental benefit is slightly more accurate, that level of data tracking makes the process burdensome and unnecessarily exact given that other approximations have to be used to calculate the environmental benefits afterwards. Proxy evaluation is less precise and might underestimate environmental benefits, but it is simpler and data is easier to track. That is why most organizations use proxy evaluations to estimate the environmental benefits of EEP/GPP.

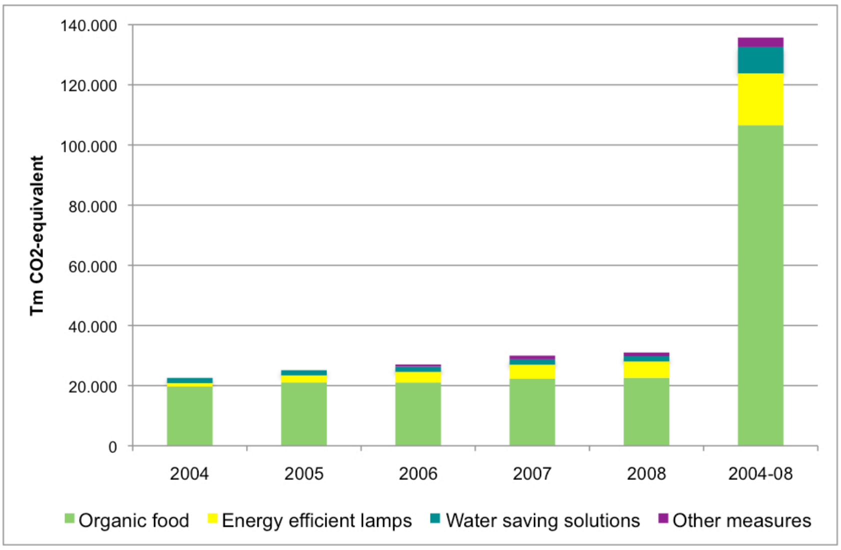
Thirdly, the environmental impact factors have to be established. This includes estimated functioning modes (for computers, it might be hours a day in “on”, “stand-by” and “off” mode and annual workdays; for vehicles annual mileage is normally used) and conversion factors. These conversion factors translate estimated consumption units into GHG emissions by energy source (for example grams of CO_2 by kWh of electricity, litre of fuel or m^3 of natural gas).

Finally, and in order to communicate how EEP has reduced energy consumption and GHG emissions, the environmental characteristics of products used previously or non-efficient alternatives have to be recorded. When doing so, it is recommended to track not only the improvement ratios between green and not-green products, but also the absolute figure to calculate the environmental relief achieved from buying less. GPP is meant to improve the environmental performance of public authorities throughout the whole purchasing cycle. Thus, the effects of these programs can go beyond buying green product and include other activities in the field of responsible consumption, such as reducing needs or using resources more efficiently. If only the environmental benefits of buying green are evaluated, an organization buying a larger quantity of products might show better results in environmental relief than another one that reduced its overall consumption. Therefore, monitoring the environmental performance on the basis of purchased products should also consider overall purchases to avoid penalizing organizations that become more efficient and reduce their purchasing needs.

Case 8. Benefits of Vienna’s ÖkoKauf Program

The green procurement program of the Vienna City Council, known as *ÖkoKauf Wien*, was set up in 1999 as one of the key elements of the city’s climate protection program, *KliP Wien*. Even though *ÖkoKauf* does not maintain detailed records of the environmental relief achieved, some calculations have been done to communicate the environmental benefits and cost reductions of the program, as there is a general misperception that ecological goods and services always come with a price premium. For the environmental component, the program calculated impacts during either the use or production phase of the product or service. For example, with organic food an estimated factor of the environmental relief during production of organic versus conventional food was used. For energy efficient lamps and water-saving devices, the impact was estimated based on the reduction of water, hot water, and electricity consumption during use [14].

Figure 4. CO_2-equivalent reduction achieved with GPP in the City of Vienna, Austria (2004-2008)



Source: Patak, G. *ÖkoKauf Wien* [slides presentation]. European Public Sector Award 2011 (Maastricht, the Netherlands 15-17 November 2011).

3.2.2. Calculations Based on Energy Consumption

Due to the influence of energy efficient products on the organisation's energy consumption, the benefits of EEP can also be calculated indirectly by monitoring the energy consumed by the organisation. For example, the reduction in vehicle fuel consumption expected from buying energy efficient vehicles can be estimated, or annual fuel consumption can be tracked to measure the actual reduction due to green procurement.

The procurement of energy efficient products and services is key to reducing energy consumption; however, product use and behaviour may have a greater impact on actual energy consumption. In fact, energy savings estimates based on purchases (see previous section 3.2.1) does not guarantee a decrease in energy consumption, and how the product is used and consumer usage habits must be taken into consideration. Therefore, whenever possible, it is best to calculate real energy savings and CO_2 reduction by monitoring actual energy consumption. This approach reduces the number of parameters to track and makes it possible to monitor the effects of green solutions without making estimates. However, as an indirect evaluation, EEP effects might be masked due to the interaction with other variables.

Case 9. Indirect Evaluation of Green Vehicle Procurement in the USA [15]

In the United States, energy efficiency improvements and GHG emissions reduction achieved in government owned vehicle fleets through green procurement actions are not monitored based on annual purchases, but indirectly through the overall performance of the improved fleet using real usage data. Through the web-based Federal Automobile Statistical Tool, agencies input data required by several regulations (both energy and economic/budget related). These inputs include: vehicle inventory, purchases and disposals (actual, planned, projected, forecast), type of fuel, type of ownership (purchased, GSA-leased, commercially-leased), mileage, cost data (acquisition, indirect, maintenance and depreciation costs), and fuel cost and consumption. Using this information, GHG emissions reduction associated with vehicle procurement and use can be calculated and integrated into the overall target for GHG emissions reduction by the federal government.

4. Supportive Instruments

4.1. Incentives

Even when monitoring is part of EEP policies, organizations' commitment to implement a policy and track progress on achievements may vary, especially when the targets or objectives are voluntary, no enforcement mechanisms are in place, and/or when policy commitments are set at a higher administration level with little or no jurisdiction over other administrations' activities.

In order to promote implementation, monitoring, and reporting some administrations have supplemented EEP policies with incentives. Two types of incentives, economic and reputational, are described below.

4.1.1. Economic Incentives

Monetary incentives reward public administrations that advance EEP implementation and may also punish organisations or departments that fail to comply with minimum green procurement levels. The economic incentive can be designed in many different ways. The following cases reflect some of those options.

Case 10. GPP Reporting Incentives in South Korea [16]

To promote the purchase of green products and reporting results, the "Korean Act on Encouragement of Purchase of Green Products" from 2011 states that the Ministry of Environment may grant environment-related subsidies preferentially to local governments with excellent purchase records of green products. This assessment is based on the annual green products records that each public institution submits to the Ministry of the Environment within the three months after the end of each fiscal year.

Case 11. Financial Mechanism to Promote Environmental Monitoring and Performance in France's Central Government [17, 18 and 19]

In 2008, the French Central Government, recognizing the unique role of the government in achieving sustainable development, passed a regulation requiring all ministerial departments to develop an Exemplary Administration Plan to achieve sustainable development in their services and operations. To guarantee a certain consistency and efficacy in the government's actions, a set of common measures and targets for all Ministries was defined, focusing on procurement, eco-responsibility (mainly consumption reduction), and social responsibility. To track compliance, mandatory annual reports are also required.

To encourage the achievement of common objectives and the integration of sustainable development in the Ministries' operations, a financial mechanism was established to accompany implementation and reporting of the plans (from 2009 onwards). The mechanism consists of a virtual fund of approximately 100 million Euros created by setting aside ("freezing") 1% of the budget that each Ministry is allocated for procurement at the beginning of each year. Each ministerial department has to report on its achievements against the commonly set targets to recover the "frozen" budget. The frozen funds are redistributed among the departments according to their performance in achieving the targets. Thus, the more targets achieved, the higher the return will be, with a minimum number of targets reached to participate in the redistribution (in 2012, at least 11 out of 18 indicators had to be met- including requirements on energy consumption, procurement of low CO_2 emitting vehicles and work related travels). Two cases may arise:

If a department does not reach the minimum threshold of indicators, it immediately loses 50% of its contribution, which will be redistributed among the departments that meet or exceed the threshold (explained below). The department can recover the other 50% if it complies with the objectives for the previous reporting year during the following year. If it still fails, the money cannot be recovered and is added to the fund for next year's distribution among those that do comply.

If a department meets or exceeds the minimum threshold, it immediately gets 50% of its contribution and benefits from the redistribution of the other portions (from them, the other departments that met the threshold, and percentages lost by other departments). The amount allocated to each ministry is proportional to its financial contribution to the fund and its performance.

4.1.2. Reputational Incentives

Comparison between peers and recognition of achievements and improved efforts can have a positive effect on policy implementation if it impacts the reputation of organizations. Agencies with low performance in certain areas become motivated to improve their results and thus their reputation. Those with higher achievements get recognition for their efforts and improve their image with stakeholders. In order to have an impact, results have to be published internally, or ideally publically, and they can be presented in two ways: 1) as a ranking or benchmark of agencies based on their results, presenting both good and bad performances, or 2) as a list of top-performing agencies based on overall results or on leadership in specific areas of EEP implementation, such as policy quality, supplier engagement, monitoring systems, etc.

These mechanisms require, in general terms:

- Defining simple indicators that easily convey the different performance levels if more than one parameter is monitored (e.g. traffic light indicator, stars rating, medals indicator, etc.).
- Evaluating organizations' performance against the defined indicators to benchmark agencies according to their results.
- Making results public through a regular publication, organization's website, awards ceremony, etc.
- Keeping the mechanism in place for a defined period of time to be able to have an impact on agencies' reputations.

To leverage the impacts from these programs the publication of results should share lessons learned and best practices from departments and organizations excelling in a particular area. These examples can help other organisations improve their performance.

<u>Case 12. Green Procurement Performance Appraisal and Award in Taiwan [20]</u>

To promote GPP implementation and recognize efforts of leading agencies, the Government of Taiwan annually evaluates agencies' performance on green procurement based on "Green Procurement Amount Reports" and rewards those with excellent performance at a public event. Performance evaluation is based on three elements:

1. Percentage of total products procured from a list of designated green products—this list covers 20 product groups including: office stationery and paper products, office ICT equipment, electronic appliances, and a set of other items such as cleaning products or paints (70 points)
2. Number of other green products purchased (10 points)
3. Activities to support GPP implementation, including training courses, communication and dissemination actions, involvement of chief officers and subordinated agencies, creative procurement, etc. (20 points)

Depending on the total points obtained, agencies can be classed as Superior, Grade A, Grade B, or Grade C. Results by class from 2002 to 2006 are summarized below:

Figure 5. GPP Performance Appraisal of Taiwan Government Agencies 2002-2006

Appraisal class	Points (out of 100)	2002	2003	2004	2005	2006
Superior	More than 90	1	26	17	16	23
Grade A	More than 80	6	33	26	38	41
Grade B	More than 70	32	0	16	7	0
Grade C	Less than 70	21	1	1	0	0

Source: http://greenliving.epa.gov.tw/GreenLife/eng/E-The_Green_Procurement_Promotion_Result.aspx

Case 13. Mayor of London's Green Procurement Code [21]

The Mayor of London's Green Procurement Code is a support service for organisations committed to reducing their environmental impact through responsible purchasing. Awareness that management and behavioural changes are as important as technical specifications to source green products, the initiative provides assistance to embed green purchasing into all aspects of the organizations.

Organisations that sign the Green Procurement Code commit to achieving progressive environmental targets and can be awarded bronze, silver, or gold status as a mark of their success, depending on the results of their progress review and the completion of a third-party audit. The progress review consists of two parts: 1) performance against a set list of management questions based on the UK Government Flexible Framework; and 2) green purchases of products and services recorded during the previous financial year. Based on the combined results of both parts, organisations can be awarded one of the three levels:

Figure 6. Level awarding in the Mayor of London's Green Procurement Code

Part two \ Part one	Bronze	Silver	Gold
Bronze	Bronze	Bronze	Bronze
Silver	Bronze	Silver	Gold
Gold	Silver	Silver	Gold

Source: http://www.greenprocurementcode.co.uk/?q=node/304

Once organizations have been audited, success is celebrated at an annual awards ceremony, and award winners are listed online and in the initiative's annual progress report.

4.2. Integration in Environmental Management Systems

Environmental Management Systems (EMS) are management approaches that serve to systematically:

- Evaluate the environmental performance, risks, and impacts of an organization's operations and activities (caused directly or indirectly);
- Establish objectives, measures, and procedures to address issues causing or threatening significant environmental impacts in order to improve the organization's environmental performance; and
- Monitor and analyze performance in implementation in order to define new actions and ensure continual improvement.

When first implemented, EMS programs tend to focus on direct impacts occurring in the organisation's facilities (e.g. water and energy consumption, waste generation and recycling, use and manipulation of hazardous products, generation of noise, odours, and gases emissions, etc.). Particularly in administrative and office buildings, the scope is soon enlarged to include indirect impacts stemming from the supply chain, including first-tier contractors and following-tier suppliers. Including procurement activities as part of EMS will serve not only to apply EEP as a measure to reduce direct impacts, but also to evaluate the overall effects of unsustainable acquisition practices and help implement EEP in a consistent manner.

As EMS requires regular monitoring of results, such systems help define and implement mechanisms for careful tracking of EEP measures. When doing so, special attention must be given to defining mechanisms and monitoring systems that yield results in line with the EEP monitoring requirements and objectives set at a policy level. In any case, EMS will monitor the impact of EEP actions, though indirectly, when tracking energy consumption.

Additionally, the integration of EEP into the EMS should foresee that adverse findings are fed into the EMS corrective action process to ensure that action is taken and EEP implementation is progressively improved.

<u>Case 14. Implementing GPP Requirements in the EMS of U.S. Department of Energy Facilities [22]</u>

Executive Order 13423 directed U.S. federal agencies to implement EMS at all appropriate organizational levels to ensure the use of EMS as the primary management approach for addressing environmental aspects of internal agency operations and activities. In order to coordinate this requirement with others on GPP, the U.S. Department of Energy (DoE) approved an internal order for all facilities managed by federal staff or contractors, requiring: 1) the implementation of EMS in all DoE sites integrated with the site's Integrated Safety Management System, and 2) the inclusion in the EMS of the objectives and targets for annual review that contribute to achieving DoE sustainable environmental stewardship goals, including those on the acquisition and use of environmentally preferable products (including energy efficient products) in the conduct of operations.

5. Conclusions and Recommendations

Even though the results and impacts of many policies that include EEP requirements are not routinely monitored, the proper tracking, evaluation, and reporting of results can yield remarkable benefits to organisations. Through monitoring, policymakers can improve efficiency and effectiveness in policy deployment by identifying areas or elements that need improvement, which will help to target supportive measures. Furthermore, making results available both internally and externally demonstrates political commitment, enhances transparency, and legitimizes the promotion of sustainable consumption and production by other sectors of society. The publication of results also promotes policy embedment by keeping each agency accountable.

Existing M&E approaches applied by different public administrations show a broad range of priorities and systems for the monitoring and evaluation of EEP. Reasons behind this diversity include the variety in policy objectives, targets and goals, the relation to other sectoral policies, the difference between policy development and implementation, the structure and level of centralization of purchasing systems or the commitment level of involved actors, among others. A clear definition of policy goals and indicators, embedment in existing tracking systems, additional facilitating measures, and visibility of results are necessary for successful and cost-effective implementation of M&E systems.

5.1. Ensure Leadership and Clearly Define Objectives, Indicators and Progress Tiers

As can be observed in Table 1, EEP requirements are generally embedded in environmental policies, creating a gap between who is responsible for defining the policy and who is responsible for implementing it. The former (usually the Environment or Energy Departments) predetermines policy objectives and targets that affect the monitoring system, but it is within the Procurement units that policies are implemented. Therefore, it is key to have procurement managers participate in developing an efficient M&E system that is accurate and representative, but not too complex or burdensome, and that is integrated in existing purchaser workflows (especially when monitoring actual procurement of energy efficient products). The same applies if EEP is monitored based on consumption levels where other staff are involved (for example fleet or building managers).

In general terms, policies tend to define overall EEP targets, however it is recommended to set progress levels and evaluate against them to encourage implementation, as green procurement requires changing habits and practices, and performance tiers convey that sense of progress and the time needed to achieve those targets. Furthermore, tiers help communicate achievements to all relevant stakeholders.

To measure success, key performance indicators have to be identified. Typical indicators used to monitor the procurement of products are the total and percentage of green products and/or tenders (in units and economic terms) in relation to the total acquired or tendered for a list of prioritized product groups. When evaluating the environmental relief obtained with EEP, as highlighted in a recent report by the Energy Sector Management Assistance Program [3], indicators such as energy consumption, GHG emissions, and even cost savings are commonly used.

5.2. Set efficient systems to monitor products procurement

M&E systems might cover different objectives; therefore, an appropriate approach should be selected for each objective and this may results in a mixed system. Regardless of the system(s) selected, it is key to accompany a M&E system with clear definitions, explanations, instructions, and verification documents (if required) to avoid misinterpretations, improve the efficiency of the organisations responsible for monitoring,, and ease the centralization of data at a pan-government level. Organisations should be able to invest less time to answer queries or verify data and more on data analysis and evaluation of results. The systems should also be tested in advance, as sometimes definitions are not as straightforward as intended, and defined with the relevant parties. Linked to this, changes in the M&E systems should be minimized to facilitate understanding, ensure data comparability, and identify trends.

In general terms, monitoring green product purchases is more burdensome than monitoring green tenders. Furthermore, with the trend to change contracting models from purchase to service contracts, it can be foreseen that tracking product consumption will be increasingly onerous, as more data will be required from suppliers. Therefore, strong relationships and good reporting habits will need to be established with contractors. When monitoring tenders, the risk is to count as “green” tenders that in the end don’t yield a green result. To avoid it, only compulsory criteria should be used to qualify tenders as “green”.

For quantitative data, an early analysis of existing tracking mechanisms (of tenders, expenditure, consumption, etc.) is advisable in order to start monitoring where data is available or to introduce the required changes for efficient and reliable data tracking. This is especially relevant when monitoring green tenders and/or acquisition of green products. To be efficient, EEP tracking has to be integrated from the beginning into the procurement process and tracking systems.

Tracking mechanisms vary depending on what is monitored; however, for quantitative indicators, it is always preferable to use public data (i.e., from e-tendering platforms) or data centrally collected (such as centralized purchases), as data tracked through questionnaires is less reliable and more time consuming. In the era of electronic information technologies, online applications and internal software are the most efficient solution for compiling information and processing it automatically. Such software can be programmed to retrieve data from other platforms (reducing data input duplication) and to produce direct calculations and graphical outputs of results and their deviation from the set targets. That requires certain standardization in procurement management software and other applications, which might not exist within an organization, let alone between different public authorities. However, when tracking systems are semi-automatic and multiple users are responsible for inputting data, providing training to understand definitions, information requirements, and tool operation (either a spreadsheet or an online platform) is key to ensure appropriate data tracking and minimize errors.

5.3. Calculate Representative Environmental Benefits

As EEP has an impact on organisations' energy consumption, in most cases it is best to evaluate the evolution in real energy consumption when calculating the environmental relief achieved with EEP, to identify if EEP yields results or if other factors are overriding them. If the environmental relief is calculated only on the basis of purchased products, benefits are only theoretical, misrepresenting the EEP impacts. In spite of that, if environmental benefits are calculated directly or by proxies based on purchased products, this has to be taken into consideration from the beginning when identifying the data to be reported, as some parameters might be necessary for a meaningful assessment (for example, to report both in expenditure and physical units). And special attention should be paid to establishing an M&E system that calculates environmental benefits not only in relation to energy efficient versus conventional products, but also in relation to overall purchases and to communicate the benefits of reducing procurement needs and rationalise acquisitions.

In those regions or agencies where green procurement is considered more expensive, it is advisable to evaluate, either as a one-time evaluation or as part of the regular monitoring, the lifecycle cost reductions achieved, to make the business case for EEP and GPP, as savings achieved with EEP can be used to compensate premium costs in other GPP actions.

5.4. Implement Facilitating Measures

In order to ensure or promote better monitoring and overall implementation, organizations might design reputational and/or economic incentives to accompany M&E systems. Reputational incentives are linked to the public presentation of results and can be designed as "rewards", when only the best are acknowledged, or as "rewards and punishment", when all departments or organizations are benchmarked, from the most to the least performing. Economic incentives can also take the form of rewards and/or penalties. In the second case, it is best when all parties agree on how the penalties are to be applied in order to minimize opposition.

Another strategy to facilitate monitoring and implementation is to integrate EEP requirements within existing EMS, as EMS requires regular monitoring of results and therefore they "force" organisations to define and implement mechanisms for careful tracking of EEP measures. When doing so, attention has to be paid to define procedures that yield results in line with the EEP monitoring requirements set at policy level.

5.5. Communicate and show results

Finally, EEP individual results (by department or administration, depending on the level of monitoring) should be published and made publicly available in order to increase government transparency and demonstrate public leadership. Visual elements such as graphics and simple evaluation and rating indicators serve to present progress in an easy-to-understand manner that can be used to openly report on government performance and to benchmark progress by each agency, fostering improvement through reputational incentives. However, reports should not focus only on results but also include information on why and how department or public agency's excelling in a particular area have achieved such results, in order to tie actions to results and share examples that can help others improve.

6. Acknowledgement

This article draws on the study commissioned by the Super-Efficient Equipment and Appliance Deployment Initiative (SEAD): Ecoinstitut. *Resource Guide on Monitoring and Evaluation of Green Public Procurement Programs*. SEAD, 2013 (expected to be published in May/June 2013).

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Energy Efficiency and the Australian Water Heating Market

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Abstract

Recent increases in energy prices have led to a focus on cost-of-living issues in Australia. Water heating in Australia accounts for approximately 25% of household energy use, second only to space heating and cooling, and plays an important role in relation to energy costs. Hot water energy use plays an important role in the magnitude and management of 'peak' electricity demand and associated grid infrastructure requirements. Over the past decade the increase in the Australian water heating market has been extraordinary. Factors attributed to driving this change include regulations, subsidy programs, technology advancements, shifts in consumer demand, fuel price inflation, carbon pricing, and changing attitudes towards water consumption. The ability for policy makers and stakeholders to develop and set appliance-specific energy efficiency requirements in a timely and efficient manner have been impacted by rapid changes in the hot water market. Decision makers established limited incentive programs to institute long-term changes in the market. The setting of hot water appliance energy efficiency requirements remains a highly effective tool and recent national legislation has streamlined processes and improved responsiveness. However, reliance on government 'push' policies may not provide optimal outcomes. New regulatory policies may be needed to improve efficiency for all hot water technologies (electric resistance, heat pump, solar, gas etc.). Information-based 'pull' policies can effectively promote new energy-efficient products, provide manufactures with greater certainty, and reduce costs for governments. New 'push' policies can help consumers make informed decisions to purchase energy efficient water heaters.

Introduction

Importance and pressures in the Australian hot water market

Water heating is responsible for approximately 25% of energy consumed in Australia's residential sector. Conventional hot water heaters are installed in nearly half of these eight million homes that in turn produce nearly three times the amount of greenhouse gas equivalents (CO_2-e) as more efficient technologies, while potentially costing significantly more to operate. The lifespan of water heaters can exceed 10 years. Therefore, the choice of a water heater can cause large and long lasting implications on consumer energy bills.

Australian water heater market shares are as follows: 52% conventional electric storage water heaters, 40% gas water heaters, 9% solar water heaters (both gas and electric), and 2% heat pump water heaters [1, 2]. The breakdown of technology by Australian jurisdiction varies substantially and is driven by factors such as different climatic conditions, availability of gas networks, and separate tariffs.

There are two broad, related sources of pressure on the Australian hot water market.

1. 'Cost of living' pressures have become a priority issue. The substantial reliance on expensive-to-operate conventional hot water heaters and increasing energy prices is creating pressure to reduce this reliance and reduce energy bills for consumers.

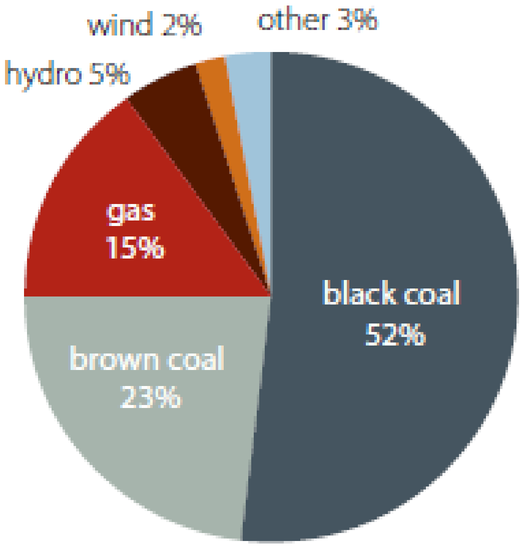
2. The hot water market remains subject to two distinct of 'market failures'. These failures can be described as information failures (inability to access independent and reliable information on the lifetime costs of various water heating technologies) and 'split-incentives' where the purchaser of hot water systems will not be responsible for the operating costs of the appliance (e.g. a landlord purchasing an inexpensive conventional water heater while the renter will ultimately become responsible for the associated running costs).

Pressures in the Hot Water Market

Pressure One – Cost-of-Living and Energy Costs

Energy Consumption and Cost Pressures

Australia is the world's eighteenth largest energy consumer and ranks fourteenth on a per-person basis. Australia's energy consumption is primarily composed of non-renewable energy sources [3]. **Figure 1** shows electricity generation by energy source in 2009-10. Coal accounts for approximately 75% of total generation, gas accounts for 15%, and renewable energy accounts for 8% (mainly hydroelectricity, wind and bio-energy). The high reliance on abundant non-renewable sources has led to recent price pressures as governments have sought to address carbon emissions though interventions such as a nation-wide carbon price (currently $AUD23 per ton of CO_2-e) and renewable energy targets.



a Other includes oil, bioenergy and solar PV.

Figure 1. Australia's Electricity Generation by Energy Source in 2009-10

Source: Energy in Australia, 2012.

Growth in peak daily electricity demand over recent years has been a significant contributor to rising electricity costs. Between 10% and 25% of maximum demand occurs for only 1% of the time, creating demand for high-cost, fast-start generation capacity and additional network infrastructure to be maintained. The two main drivers causing the growth in inefficient peak demand are the increased use of relatively low−cost, energy-intensive domestic appliances and inefficient pricing structures [4]. More recently, there have been declines in average annual consumption and reduced rates of peak demand growth, but these trends have yet to impact retail prices.

Australia's gas market is undergoing major transformation, including increased demand competition and rising costs of production from new gas fields. While Australia has adequate overall gas reserves to meet projected domestic demand and exportation needs until at least 2035, there may be some transitional tightness in the east coast gas market as new coal-seam gas and LNG projects ramp up to full production. These factors are already manifesting in higher gas prices and tighter supply dynamics.

Impact on Cost-of-Living

Rising electricity and gas prices are affecting the costs-of-living of many Australian households. Recent increases in power prices reflect mainly increases in network costs caused by a complex combination of increasing peak demand, replacing and augmenting ageing infrastructure, as well as a marginal impact from various energy efficiency and renewable energy policy interventions at both the state and national levels [4]. Australia's electricity prices were slightly below the Organization for Economic Co-operation and Development (OECD) average in 2010. Since that time there has been rapid price increases in most areas of Australia. Retail electricity costs have increased on average by around 40% in the past three years, and by well over 50% in certain regions.

Pressure Two - Market Failures

Information Failures

A rational, informed consumer wishing to minimise the 'lifetime-cost' of purchasing a water heater would ideally research and take into account both the initial purchase cost and the projected running costs associated with the appliance. Water heaters are purchased in drastically different ways than other household appliances which complicates the ability to make informed decisions. Market research shows 'people usually understand the appliance, a range of makes and models is readily available and able to be directly compared in showrooms, and energy usage parameters are simple as the appliance is on all the time…the decision regarding a water heater is often unexpected (water heaters rarely give warning of problems), hasty and ill-considered. The current study clearly identifies that the appliance installer (plumber and/or electrician) has a primary role to play in the water heater decision' [5].

BIS Shrapnel quantified the magnitude of information failures in a survey on purchasers of water heaters. They found that 22% of water heater buyers conducted no research at all in purchasing a water heater and 66% of conventional electric storage water heater buyers considered no alternatives. Low consideration of alternative water heating technologies with significantly lower operating costs suggests that consumers may not be aware of options available [6].

The market failures relating to energy efficiency were also investigated. The nature and implication of the informational market failure was described as, "residential consumers are poorly informed when it comes to retail electricity arrangements, the price of electricity and how their electricity consumption impacts on their bill. As a consequence, consumers have been unable to choose retail electricity offers better suited to their needs or modify their electricity consumption in ways that would help minimise their electricity costs" [7].

The Select Committee described energy efficiency as 'the "low hanging fruit" of electricity consumption and emissions reduction efforts and as 'the easiest, simplest and most cost efficient' tool to meet these goals. The report also noted arguments that energy efficiency efforts should focus on heaters, air conditioners and hot-water systems as these appliances can offer faster payback periods and will result in 'material' rather than 'symbolic' benefits to households.

Split Incentives

A split incentive situation can arise when an agent (landlord, plumber or builder) is acting on behalf of a principal (buyer, tenant) and therefore may have different motivations. The split incentive is caused an insufficient focus on the likely running costs of the water heater which will be payable by the end-user, rather than the agent. It is estimated that approximately 20% of sales may be affected by a builder/owner split incentive while at least 30% of sales may be affected by a landlord/tenant split incentive. The purchase and installation cost of an average conventional electric water heater in 2012 was approximately $800 cheaper than a heat pump water heater, however the latter can offer savings of $330 per annum. 270,000 conventional water heaters are estimated to have been sold in Australia in 2011 and 50% may have been affected by split incentives; clearly the implications of sub-optimal purchases are substantial.

Impact of Failures

Due to the sheer number of expensive-to-operate conventional water heaters, there is significant opportunity for Australians to shift to more efficient water heating technologies. However, information failures reduce the ability for a consumer to easily identify and understand the lifetime benefits of more efficient heaters. Since up to half of all water heater purchases may be driven by the upfront cost of the heater rather than the lifetime operational costs, there is vast room for informational improvement.

Current Hot Water Market – Trends and Current Interventions

Technological and Consumer Trends

Australia has recently experienced a high level of technological advancement in the water-heating sector. In recent years the heat pump water heater sales have rapidly risen as shown in **Figure 2**. Established technologies, such as solar water heaters, have also continued to be refined with in-line boosting rather than tank boosting becoming increasingly common.

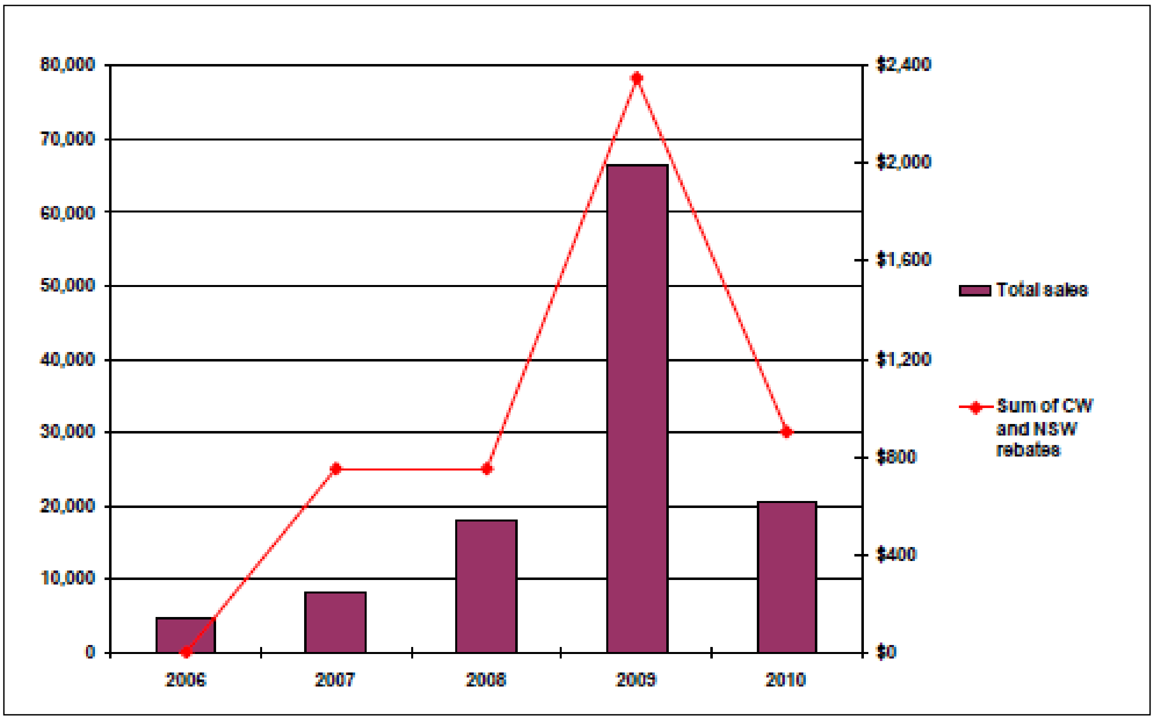


Figure 2. Heat pump water heater installations by year

Source: Product Profile: Heat Pump Water Heaters, Equipment Energy Efficiency Program June 2012.

The issues facing consumers are more complex than just water heating priorities. With increasing energy bills there can be trade-offs in consumer purchasing habits such as diverting their funds to more efficient water heating products or to reducing their net-power demand through actions such as installing solar PV. While the number of solar hot water installations has historically overshadowed solar PV, both experienced significant growth since 2009 as shown in **Figure 3**. In 2011, solar PV installations overtook solar hot water, especially as installations of the latter declined.

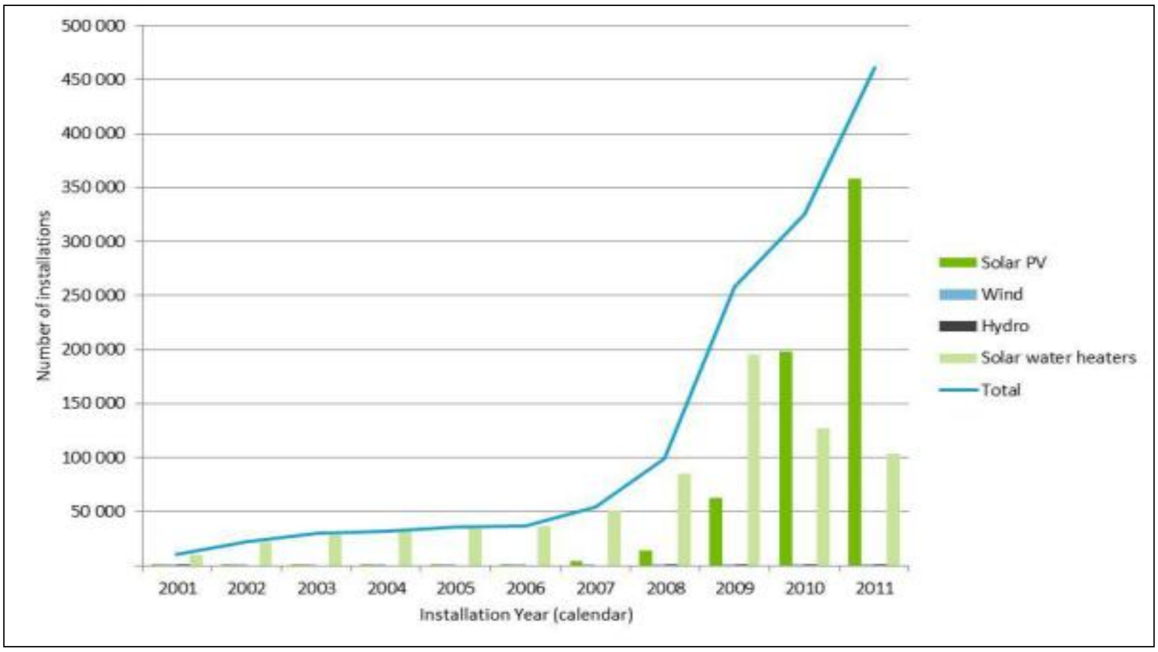


Figure 3. Number of installations of small-scale systems

Source: Renewable Energy Target Review – Final Report, Climate Change Authority, December 2012

From 2003 to 2012 many parts of Australia experienced a severe drought with various degrees of water usage restrictions imposed. While the drought did not explicitly alter the market for hot water appliances, a stronger focus on water efficiency emerged. Through general consumer action, construction requirements, and other government initiatives lower levels of demand may now impact the average hot water appliance. There has also been new areas of consumer concern in purchasing water heaters – such as an interest in the amount of water an 'instantaneous' water heater may supply before providing peak hot water temperature.

There are many factors that led to the above changes in consumer behaviors such as changing electricity tariffs, solar 'feed-in' prices, government subsidies, and decreases in solar PV costs. This is a good example of how different elements can rapidly change the market in a short period of time. This makes the need for efficient government intervention critical to achieving desired policy outcomes.

Limitations to Current Government Interventions

The Australian hot water market is currently subject to a number of energy usage or energy efficiency related interventions. The most significant include:

1. Subsidies for solar and heat pump water heaters based on potential energy displacement

2. Electric storage water heaters - maximum tank heat loss limits

3. Gas water heaters - an industry managed label as well as government managed maximum annual gas consumption levels

4. Government mandated installation codes specifying minimum 'star ratings' for gas water heaters and minimum energy displacement levels for solar and heat pump water heaters

5. An economy wide carbon price scheme which assists in internalizing economic externalities associated with the CO_2-e emissions For water heaters the impact of the carbon price is largely through increased electricity or gas prices, although the carbon intensity of such inputs vary across the nation.

While assessing the level of success of the above interventions is outside the scope of this paper, some broad observation about the limitations of the above policies can be noted.

Subsidies

In relation to subsidy-based programs Australia is facing challenging fiscal circumstances. While rebates can be effective in influencing consumer purchasing decisions, maintaining rebates of sufficient magnitude, scope, and duration to permanently shift the market is expensive. Additionally, there is the potential for disruptions to industry when such programs commence or cease. While carefully targeted programs can deliver strong net-benefits, it is unlikely that the more broad and persistent market failures can be solved by subsidy programs alone.

Minimum Energy Performance Regulation

Regulatory intervention in the form of minimum energy performance metrics can be justified where it provides an economic net-benefit. Australia, like many OECD nations, has a robust regulation impact assessment (RIA) framework that ensures all interventions are well designed and model the national net-cost. As part of the RIA framework, appliance energy efficiency interventions typically require three significant technical reports produced over a series of years to ensure that an appliance under investigation is suitable for regulatory intervention, to ensure that stakeholders have multiple opportunities to provide feedback and the eventual decision makers can be provided a range of reform options. Even if this process results in an agreed upon regulatory option, implementing the decision through changes to national Standards as well as providing sufficient notification time can take years.

Performance metrics can be a powerful tool in improving appliances and aid in mitigation of problems. However, the regulatory process is both time and resource intensive and as such is poorly suited to take advantage of rapid changes in technology or consumer preference. Such regulation can help address split-incentive issues but ultimately has little effect on market information failures.

Installation Requirements

Installation requirements are an effective tool for minimising split-incentives by effectively banning the worst performing products. However, installation requirements often require an established and suitable metric upon which to base the aforementioned requirements. Where ideal benchmarks do not exist, installation codes can be based on ‘proxy’ requirements. For example, in the energy efficiency sections of the National Construction Code for residential buildings, requirements for solar water heaters and heat pump water heaters are based on energy displacement metrics, not energy efficiency metrics. While the energy displacement metrics may improve the overall outcome, issues such as oversizing can result.

Increasing the Responsiveness of Government Intervention

Each key water heating technology will still be subject to an investigation of minimum level of acceptable energy efficiency along with possible additional requirements to ensure that the products are fit-for-purpose. However, as such interventions need to proceed cautiously through a comprehensive RIA process while issues facing consumers constantly evolve, reliance on such defined government ‘push’ policies may not provide optimal outcomes.

Labelling initiatives that provide customers with simple and easy-to-understand information are key to overcoming current market failures. Educating customers will not only address current information failures, but an information-based ‘pull’ approach will also immediately capture new products. If a particular technology offers the best outcome, the market will be able to quickly shift to that specific appliance type. This will place a higher onus on all manufacturers and importers to ensure that their products are competitive in regards to both cost and energy efficiency. An information-based approach may also provide manufactures with a higher level of certainty as well as reducing overhead government costs. An example of such a consumer information initiative is the climatic hot water labelling framework currently being pursued in the EU[1].

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[1] http://www.eceee.org/Eco_design/products/water_heaters/

Conclusion

Given the increasing focus on the price of energy and cost-of-living, government interventions into the Australian hot water market can offer significant net-benefits. Government policies need to address current market failures in the form of split incentives and informational failures in order to optimise efficiency. While government 'push' policies such as rebates and minimum energy performance standards play a very important role in achieving policy goals, such tools may not be able to keep pace with the rapid level of change occurring in the water heating market. Information-based 'pull' policies can promote new energy-efficient products, provide manufactures with greater certainty, and reduce costs for governments.

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Avoiding 100 New Power Plants by Increasing Efficiency of Room Air Conditioners in India: Opportunities and Challenges

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Abstract
Electricity demand for room ACs is growing very rapidly in emerging economies such as India. We estimate the electricity demand from room ACs in 2030 in India considering factors such as weather and income growth using market data on penetration of ACs in different income classes and climatic regions. We discuss the status of the current standards, labels, and incentive programs to improve the efficiency of room ACs in these markets and assess the potential for further large improvements in efficiency and find that efficiency can be improved by over 40% cost effectively. The total potential energy savings from Room AC efficiency improvement in India using the best available technology will reach over 118 TWh in 2030; potential peak demand saving is found to be 60 GW by 2030. This is equivalent to avoiding 120 new coal fired power plants of 500 MW each. We discuss policy options to complement, expand and improve the ongoing programs to capture this large potential.

1 Introduction
Room air conditioner (AC) demand is growing rapidly at rate of 20% on average per year over the last ten years and is likely to be a major contributor to the need for new power plants in India. In 2010, the room AC saturation amongst urban households was only 3% compared to 100% in China ([1], [2], [3]). With rising incomes and urbanization, falling AC prices, and a hot climate, it is expected that the AC ownership is going to rapidly increase in India. Based on the projections in [4], the authors have estimated the electricity demand from ACs to increase to 239 TWh/yr by 2030, which translates to a peak demand contribution of about 143 GW. Meeting this demand requires construction of nearly 300 new coal fired power plants of 500 MW each. We show in this paper that the efforts to accelerate the adoption of efficient ACs can lead to reduction of the AC demand by more than 40% cost effectively; this translates to avoiding building more than 100 new power plants. Since most of the AC stock in India is yet to be purchased, the demand could be reduced at lower costs if the actions are taken now compared to actions taken after most of the stock is installed.

Limited technical and economic analysis exists on options to improve the efficiency of room ACs in India, the cost effectiveness of these options, and the total saving potential. In this paper, we undertake a detailed engineering-economic assessment of the efficiency potential of room ACs in India and verify some of our findings using efficiency and prices observed in the market.

In section 2, we summarize the current status of the room AC efficiency and related policies in India, and compare them to other countries and regions. We show the engineering options to improve the efficiency of room ACs and the costs of these options in India, and estimate the cost of saving electricity by implementing these options in section 3. In section 4, we present the correlation of air conditioner ownership with income and weather, and estimate the electricity demand from room ACs in 2020 and 2030. In section 5, we estimate the total electricity and peak demand saving potential by improving the efficiency of room ACs. In section 6, we conclude the analysis by providing insights for policies and programs to accelerate the penetration of efficient ACs and realize the electricity savings.

2 Current status of room AC efficiency and related policies

2.1 Status of the room AC market

AC market in India is dominated by room ACs, which make up nearly 99% of the annual sales [5]. The room AC market in India has seen a rapid growth in the last several years as shown in the following chart. Since 2004, except the small drop in 2011, room AC sales have grown at an average annual growth rate of 17%.

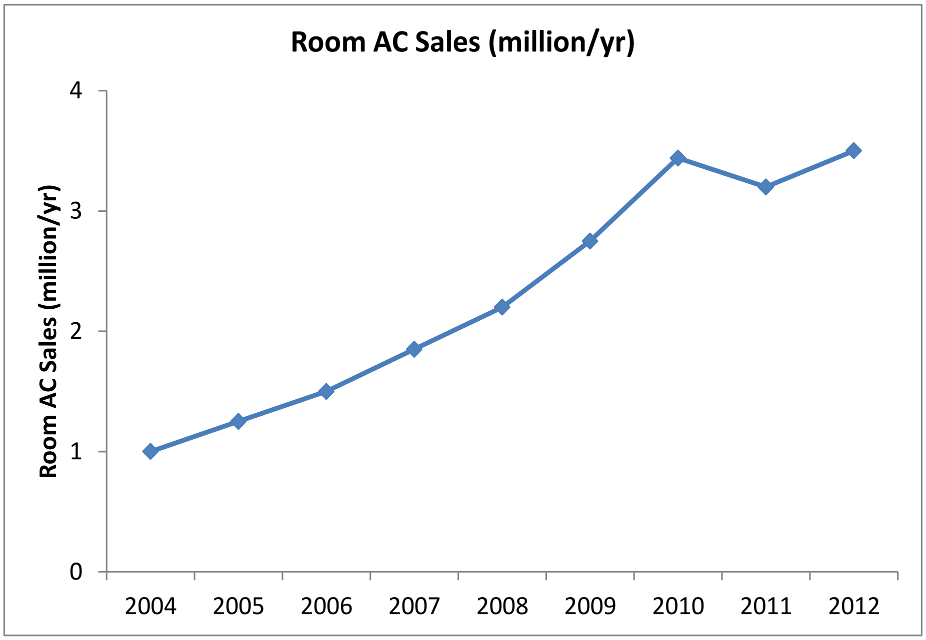


Figure 1: Sales of Room ACs (split and window units) in India

(Data Source: [6])

The Room AC market is increasingly dominated by split ACs (split-packaged non-ducted units). In the financial year 2011-12, split units accounted for 75% of the total room AC sales, while the window units (single packaged non-ducted) accounted for the remaining 25% [6].[1] Rooms ACs are primarily used in the residential, and small and medium commercial sector. According to [5], about 80% of the window units and 50% of the split units are sold in the residential market; moreover, the current market trends indicate that share of the residential sector is increasing faster than that of the commercial sector [7].

2.2 Status of efficiency and related policies

Since 2006, the Bureau of Energy Efficiency (BEE), a nodal agency for implementing energy efficiency policies in India, has initiated a standards and labeling (S&L) program for different electrical appliances. The energy efficiency labels in India are given in the form a star rating - from one-star to five-star; five-star being the most efficient. The labeling program has been made mandatory for all room ACs sold in India since 2012. This implies that any room AC must earn at least the one-star label before it could be marketed in the Indian market. Therefore, the efficiency level for one-star label serves as the de facto Minimum Energy Performance Standard (MEPS). The following chart shows the current and future ranges of the energy efficiency ratios (EER) for different star ratings in India.

[1] The Indian financial year starts in April and ends in March. For example, financial year 2011-12 started in April 2011 and ended in March 2012.

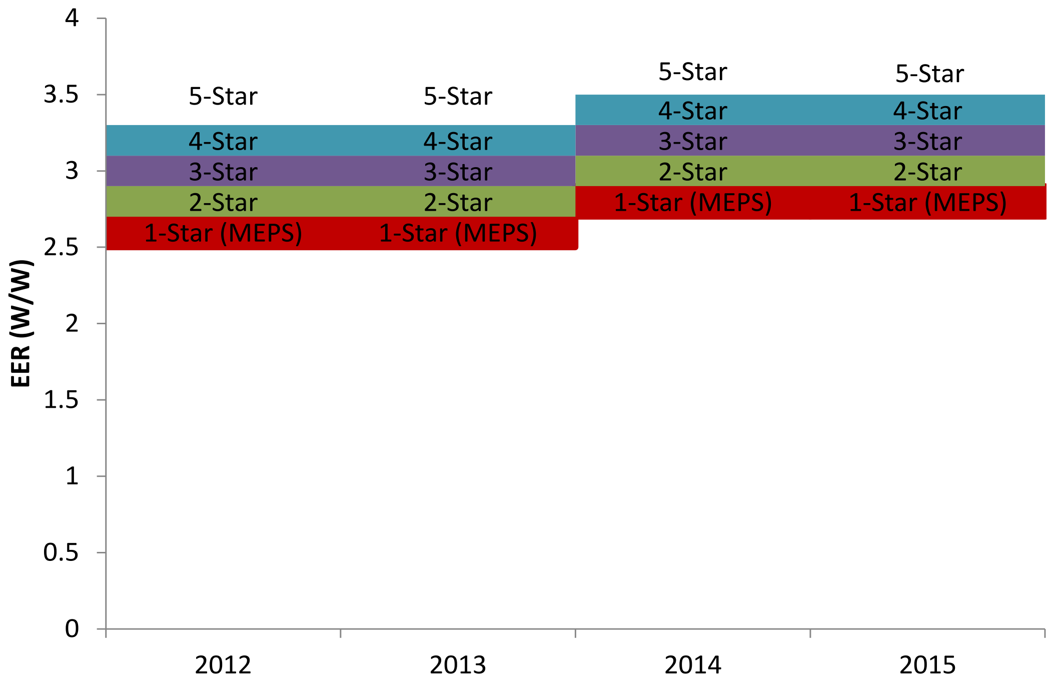


Figure 2: Current and Future Schedule of energy efficiency labels for Room ACs (split units) in India

(Data Source: [8])

It can be seen from the chart that the current MEPS for split ACs in India is an EER of 2.5, which is scheduled to increase to 2.7 by January 2014. Similarly, all ACs with EER of 3.3 and above are currently labeled as 5-star, which is scheduled to increase 3.5 by January 2014.

MEPS and maximum efficiency labels of the Indian room ACs, however, are significantly lower than that compared with other countries as shown in the following table.

For countries which implement product specific MEPS (all countries shown in the table except Japan and South Africa), the minimum EER is influenced by MEPS whereas the average and the maximum EER depend on several factors such as market conditions, energy efficiency policies etc. Compared to several countries, MEPS in India is less stringent. For example, in China, the MEPS is 16 % more stringent than India; the average EER of the Indian room AC market is comparable with the products with lowest energy efficiency rating in China.

Table 1: Minimum, Maximum and Average EER (W/W) in the room AC market (split units) in different countries (illustrative)[2]

	EER (W/W)		
Country	**Min**	**Max**	**Average**
Australia	2.67	4.88	3.16
Brazil	2.92	4.04	3.19
Canada	2.14	4.33	3.6
China	2.9	6.14	3.23
EU	2.21	5.55	3.22
India	2.5	3.8	2.9
Japan	2.37	6.67	4.1
Korea	3.05	5.73	3.78
Mexico	2.42	4.1	2.92
Russia	2.5	3.6	2.79
South Africa	2.28	5	2.91
UAE	2.14	3.22	2.69
USA	-	4.6	3.04

(Data Source: [9], [10])

We understand that the EER values are not directly comparable across different countries because of the minor differences in the test procedures followed in each country. Moreover, comparison of the MEPS and market average EERs between different countries offer few insights for improving energy efficiency policies and programs. This is primarily because of the differences in the weather conditions, usage patterns, electricity rates, and discount rates across countries. These factors influence the efficiency of the air conditioners in the market as well as the level of MEPS. Therefore, in this paper, we assess the cost-benefit of improving efficiency of room ACs only in the Indian context.

3 Techno-economic analysis of efficiency improvement options for Room ACs in India

In this section, we first summarize the efficiency improvement options considered, the amount of efficiency gains, and estimate the corresponding incremental costs. We then estimate the cost of conserved electricity (CCE) for each of these options, and then compare it to the cost of supply from several perspectives to provide insights into the cost effective efficiency improvement levels.

3.1 Various options to improve the efficiency of the room ACs

Following on from [9], we present a list of design options that can improve the efficiency of room air conditioners and estimate the incremental cost of such options. In this paper, we have considered only such design options that can be directly applied within the standard room air conditioner technologies currently on the market; these options will show energy savings under the existing product energy performance test procedures and they can be integrated into current products (i.e. do not imply changing the basic product configurations). The following room air conditioner features were considered for design improvements, namely: compressor efficiency, compressor control, heat exchanger performance, expansion valves, crankcase heaters and controls, and standby power use [9]. For each design option, there are up to five levels of efficiency improvement. The following table summarizes these options, levels of efficiency improvement, possible efficiency improvement over the base case and incremental manufacturing cost.

[2] This data should be treated as illustrative as no overlapping datasets were available to cross-check these data points. [9], [10].

Table 2: Summary of the efficiency improvement options and incremental manufacturing cost

	Base Case (Market Average)	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Option 1: Compressor Efficiency (Increase compressor efficiency)	Base case compressor	**6.5%** improvement at Rs 1,310	**12.3%** improvement at Rs 4,138	**18.7%** improvement at Rs 12,270		
Option 2: Compressor Control (Variable speed drives)	Single-speed compressor control	**20%** improvement at Rs 4138	**20.7%** improvement at Rs 8067	**24.8%** improvement at Rs 11996		
Option 3: Heat Exchanger (Increase exchanger efficiency)	Base case heat exchanger	**9.1%** improvement at Rs 3391	**16%** improvement at Rs 7271	**21.3%** improvement at Rs 11122	**24.8%** improvement at Rs 14948	**28.6%** improvement at Rs 18753
Option 4: Expansion Valve (Use thermostatic or electrostatic valves)	No expansion valve control	**5%** improvement at Rs 728	**8.8%** improvement at Rs 2038			
Option 5: Crankcase heater efficiency and crankcase heater control (increase efficiency & reduce heating period)	Base case crankcase heating and control	**9.8%** improvement at Rs 1048	**10.7%** Improvement at no incremental manufacturing cost.			
Option 6: Standby (Reduce standby load)	Base case standby loads	**2.2%** improvement at Rs 786				

(Source:[9]

Note: 1. EER for the base case air conditioning unit is taken as the market average EER.
2. All the efficiency improvement numbers are relative to the base case.
3. Design options 2, 4 and 5 require a seasonal metric to show savings and will not show savings under EER metric even though annual energy consumption may be lower, due to savings during operation at partial load.)

The efficiency gains associated with these options depend on the seasonal load characteristics assumed and hence depend on the climate and usage factors. In India, a room air conditioner is assumed to run for about 8 hours every day for 6 months in a year i.e. 1440 hours/year. This assumption is in agreement with multiple other sources such as [10], [11], [12], [13].

3.2 Incremental Costs of Efficiency Improvement

Table 2 shows the incremental manufacturing cost for each design option. However, the final price that the customers pay (which we term as the installed cost) includes the manufacturer's selling price, installer margin and tax. To arrive at the installed cost for each design option, we have used a set of multipliers developed in [9], which represent the mark up from the original manufacturer's cost.

The following chart shows the total manufacturing cost and total installed cost against the EER for each design option. The chart also shows the actual retail price in the Indian market for a few room AC units selected randomly against their EERs. The retail price data was taken from www.compareindia.com.

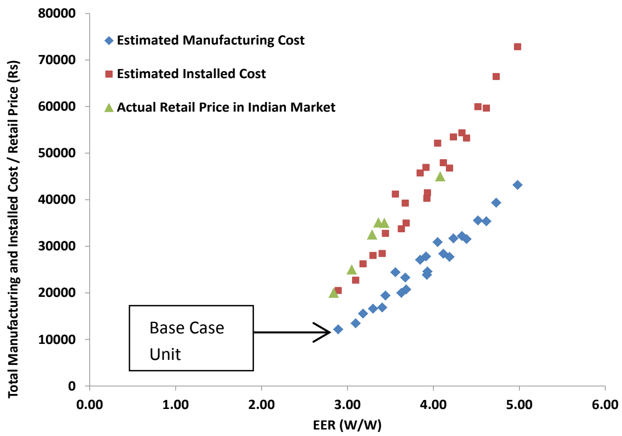


Figure 3: Total Manufacturing Cost, Installed Cost and Actual Retail price for a range of EERs

(Data Source: [9], [14])

3.3 Cost-Effectiveness of Efficiency Improvement

3.3.1 Cost of Conserved Electricity

In this analysis, the cost effectiveness of efficiency improvement options and the corresponding savings potential is assessed by comparing the cost of conserved electricity (CCE) for these options with the cost of electricity. CCE is estimated by dividing the incremental cost of the design change by the incremental energy saving due to the efficiency gain.

$$CCE = \frac{Annualized\ incremental\ cost\ of\ efficient\ AC}{Annual\ electricity\ saved\ by\ efficient\ AC}$$

CCE, therefore, could be readily compared against the consumer tariff or the marginal cost of supplying electricity. If the CCE is lower than the consumer tariff, it will be cost-effective for consumers to invest in the efficient AC. Similarly, if the CCE is lower than the long run marginal cost of electricity, investing in a market transformation program would be cost-effective relative to building new power plants.

In this analysis, we have estimated two types of CCE: cost to the manufacturer of conserved electricity, CCE_m and cost to the consumer of conserved electricity, CCE_c. CCE_m uses the incremental manufacturing cost, while CCE_c uses the incremental installed cost of the higher efficiency models. Naturally, CCE_m is lower than CCE_c because it does not include the distributor markups and installation costs. Therefore, CCE_m can be used to measure the cost-effectiveness of a market transformation program such as an upstream incentive program, while CCE_c would be used to measure the cost effectiveness of a standards program or a downstream incentive program targeting the consumer [9].

We understand that the seasonal energy efficiency ratio (SEER) provides a fuller picture of the energy efficiency of a room AC, since it captures AC operation at partial loads. However, in India, MEPS and labels are prescribed using EER; therefore, in this paper, we have chosen to use EER as the efficiency. If SEER metric is used, potential energy savings could be higher by nearly 20%, if part load conditions are prevalent often [9]. For more discussion on EER and SEER, refer to [9].

3.3.2 Electricity costs and consumer tariffs in India

Consumer tariffs in India include government subsidies and cross subsidies among consumer classes. However, under the current power sector reforms, there is a strong push for tariff rationalization and reduction of the amount of such cross-subsidy. The domestic fuel sector in India (mainly coal and gas) is severely constrained. Therefore, most of the marginal generation capacity addition is coming in the form of imported coal or imported LNG. Imported coal prices have been increasing in the world market and are significantly above the domestic coal prices in India. The following table shows the average consumer tariffs and the long run marginal costs of electricity supply (including the transmission and distribution costs).

Table 3: Consumer Tariffs and Long Run Marginal Cost of Power Supply

Consumer Tariffs	
Average residential tariff (Rs/kWh)	4.5
Average commercial tariff (Rs/kWh)	6.0
Long Run Marginal Cost of Electricity Supply	
Cost of generation – imported coal (Rs/kWh)	3.5
Transmission and distribution loss %	15%
Transmission and distribution cost (Rs/kWh)	1
Long Run Delivered cost of electricity supply (Rs/kWh)	5.12

Note: The cost numbers shown here are the 2013 values and do not account for discount rates.

(Data Source: Authors' calculations)

3.3.3 Cost-Effective Electricity Saving Potential

The following chart shows the cost of conserved electricity from consumers' perspective (CCE_c) against the EERs of all the design options discussed in the earlier sections. It also shows the average consumer electricity tariff for residential consumers and the long run marginal cost of electricity supply. As shown in the chart, CCE is lower than the consumer tariff up to an EER of nearly 4.21; this implies that from consumers' perspective, achieving an efficiency gain up to an EER of 4.21 is cost-effective i.e. consumers would be better off if they bought an AC with EER of up to 4.21. This makes a strong case for setting the MEPS at the cost-effective EER from consumers' perspective. From the utility's perspective, the long run marginal cost of power supply is higher than the CCE up to an EER of about 4.7; this implies that the utility would find it cost effective to offer a downstream incentive (like a consumer rebate) than investing in a new power plant.

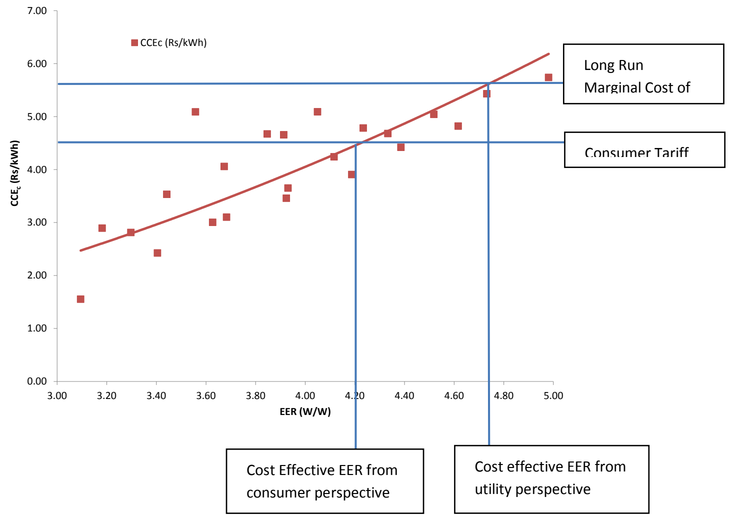


Figure 4: Cost of Conserved Electricity and Cost-effective energy saving Potential

4 Current and future electricity demand from Room ACs and energy and peak power saving potential

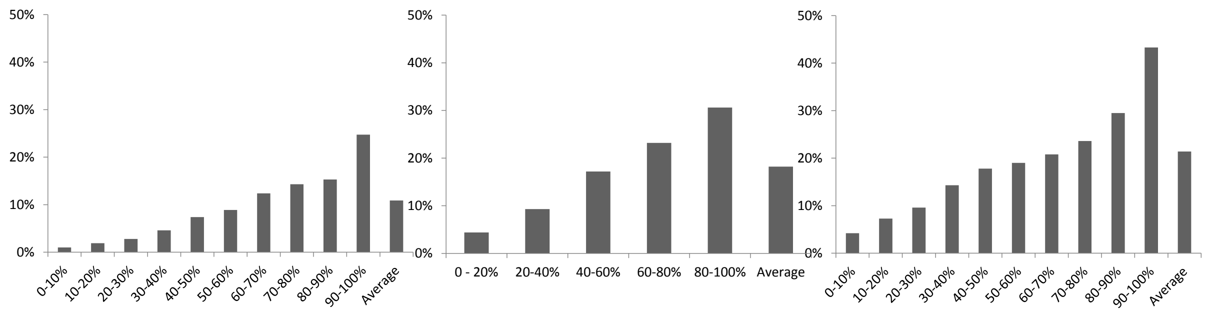
In this section, we estimate the current AC stock in India and project the future demand for air conditioners in India and their contribution to total electricity consumption and peak demand.

4.1 Future Demand for Air Conditioners

Ceiling fan is the most common household and commercial appliance used for space cooling in India. However, the saturation level of ceiling fans in urban households is more than 90% [1]. The demand for other space cooling appliances like air coolers and air conditioners has been increasing rapidly, as shown in the subsequent sections of this paper.

4.1.1 Current Stock of Air Conditioners in India

Unfortunately, national level electric load survey is not conducted in India. The national sample survey, conducted by the ministry of program implementation and statistics of the federal government of India, does collect information on household appliances; but it reports air coolers and air conditioners together. The following chart shows the total saturation of air conditioners and air coolers in the urban Indian households over the last ten years by expenditure class.



(a) 1999-2000 **(b) 2004-2005** **(c) 2009-2010**

Figure 5: Saturation of air conditioners and air coolers in urban Indian households by expenditure decile

(Data Source: [1], [2], [15])

There are two important observations that can be made from these charts, namely: (a) ownership of air coolers and air conditioners has increased significantly across all income classes. On average, the penetration of air coolers and air conditioners has doubled between 2000 and 2010. The increase in ownership in the top 2 income deciles is even more striking. (b) There is a non-linear relationship between incomes and the ownership of air coolers and air conditioners. The appliance ownership in the highest expenditure decile is significantly higher than that in the lower deciles.

In major cities like Delhi, where the temperatures and incomes are higher than the national average, the air cooler and air conditioning appliance penetration is significantly higher. Note that, on average, air conditioners account for about 15% of the total air cooler and air conditioner saturation. However, in the higher expenditure brackets and in urban areas with higher average incomes like Delhi, the share of air conditioners is as high as 30-60% [2], [16]. This implies that, on average, the saturation of room ACs in the urban Indian households in 2010 was about 3.1% (15% of the air cooler and air conditioner ownership). While average household incomes have risen significantly over the last decade, prices of electrical appliances have dropped in real terms. Most of the major Indian cities are populous and have very high number of cooling degree days compared to other cities in the world.

In short, Indian cities have significantly high cooling requirement; the AC and air cooler ownership in India shows a strong correlation with urbanization and income, and there is a non-linear relationship between income and AC ownership. Moreover, a few media reports have indicated that the share of air coolers in the Indian market is slowly being taken over by air conditioners. With rising incomes and falling prices, room AC penetration is expected to increase rapidly in India.

4.2 Projecting the Future Room AC Stock

The example of China is illuminating for understanding the rapid growth in household appliance ownership as a result of rising incomes and urbanization. The saturation of air conditioners in urban China went from nearly zero in 1992 to about 100% by 2007 i.e. within a span of 15 years [3]. Because of the factors mentioned in the previous section, we believe that the AC ownership in India is may witness a similar growth. In this paper, we have estimated the future AC stock based on [4]. The future stock is estimated by dividing the electricity saving projected in [4] by unit energy consumption of the efficient AC. The stock projections are shown in the following table.

Table 4: Room AC Consumption and Stock in 2020 and 2030

	2010	2020	2030
Total Electricity Consumption by room ACs for Business as Usual (BAU) (TWh/yr)	8	77	239
Total stock of room ACs (millions)	4	37	116
Room AC penetration in urban areas (total stock as % of urban households)	3%	22%	47%

(Data source: [1], [4], authors' calculations)

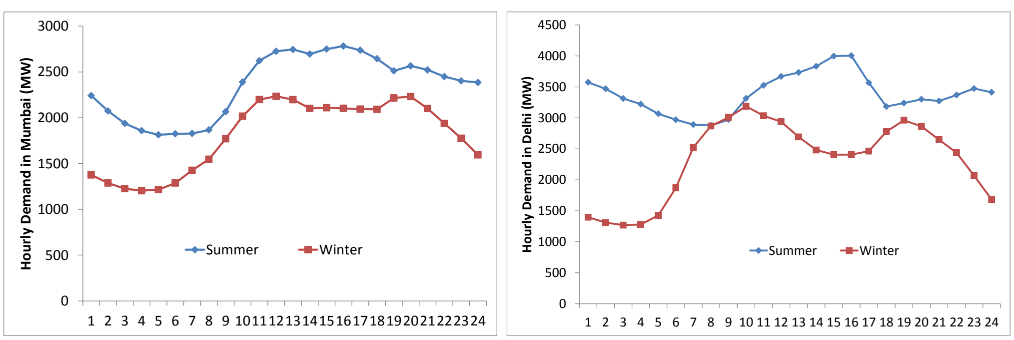
As shown in the table, we estimate that about 22% of the urban households will own a room air conditioner by 2020 and about 47% would own a room air conditioner by 2030. Given the projected incomes and urbanization in India, we believe that these are fairly conservative estimates of the future AC stock.

4.3 Contribution of ACs to the Peak Electricity Demand

In this section, we describe the usage pattern of the space cooling load in India and assess the impact of high penetration of room ACs on peak demand.

Several load surveys in India have found that the space cooling demand in India is highly coincident within a sector and also with the peak demand [11], [13], [16], [17]. Based on these surveys, the following observations could be made: (a) If a household or a commercial establishment owns an AC, its contribution to the peak demand is significant, (b) Residential and commercial space cooling demand has a significant seasonal correlation, (c) diurnally, residential AC demand peaks at night and commercial AC demand peaks in the afternoon. But during the afternoon, there are a few hours where residential and commercial demands coincide, and (d) space cooling is the only end-use that shows significant seasonal variation.

The following charts show the hourly system demand curves on average summer and winter days in two major Indian cities: Mumbai and Delhi. More than 75% of the load in these cities is residential and commercial; moreover, these cities have a modest level of AC penetration in the residential and commercial sector. Therefore, the system level data essentially represents the pattern in which these two consumer types use the electricity.



(a) Mumbai **(b) Delhi**

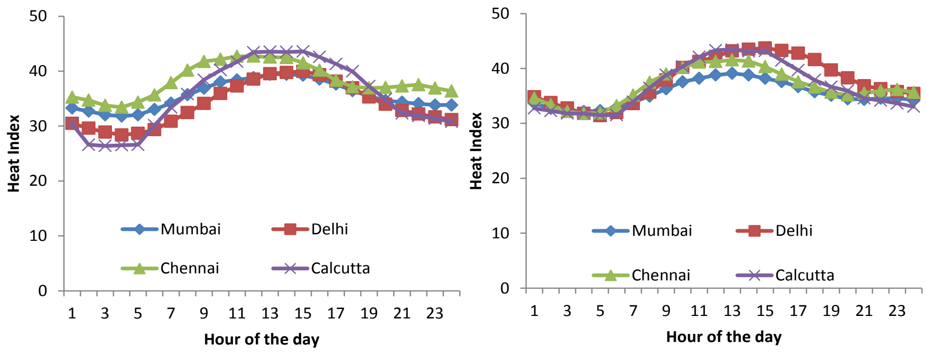
Figure 6: Average Hourly Demands in Summer and Winter in Mumbai and Delhi

(Data Source: [18], [19])

Both Mumbai and Delhi systems are afternoon peaking in the summer; coincidence of the residential and commercial space cooling demand in the afternoon causes the system demands to peak in summer afternoons. Since space cooling is responsible for the seasonal variation in electricity demand in both sectors, the peak demand in winter drops by nearly 40% and 25% respectively in Mumbai and Delhi.

4.4 Coincidence of the space cooling demand across regions in India

So far, we have shown that the space cooling demand from residential and commercial sector makes a significant contribution to the peak demand. The following chart shows the hourly heat indices in four large Indian cities located in different geographic regions in the country.



(a) May (b) June

Figure 7: Average Hourly Heat Indices of Major Indian Cities in May and June

(Data Source: [20])

It can be seen that the average heat index pattern during the summer months in India is very similar across geographic regions in India. There would be some daily variation due to local conditions, but in general, the space cooling demand may have a high peak coincidence across geographic regions.

4.5 Estimation of the Peak Demand from room ACs

Because of the reasons mentioned in the previous section, we have assumed a peak coincidence factor of 0.7 for the room ACs in India. The demand for space cooling would peak during summer afternoons. The following table shows our estimates of the peak demand contribution from room ACs.

Table 5: Projected Peak Demand from room ACs

	2010	2020	2030
Total stock of room ACs (millions)	4	37	116
BAU Electrical load per AC (W)	1500	1500	1500
Peak Coincidence factor	0.7	0.7	0.7
T & D Loss	15%	15%	15%
Peak demand contribution from room ACs (GW)	5	46	143

Note that because of the daily variations in heat indices, the actual peak coincidence and therefore the peak demand contribution from ACs may be more or less than what we have estimated. More work is needed to account for such variations possibly by introducing random variables while estimating the daily peak demands.

5 Saving Potential

5.1 Energy Saving Potential

Based on the efficiency improvement design options discussed in the previous sections, the total technical potential for saving electricity by improving efficiency of the room ACs in India is found to be 118 TWh at bus-bar in 2030. The efficiency supply curve is shown in the following chart:

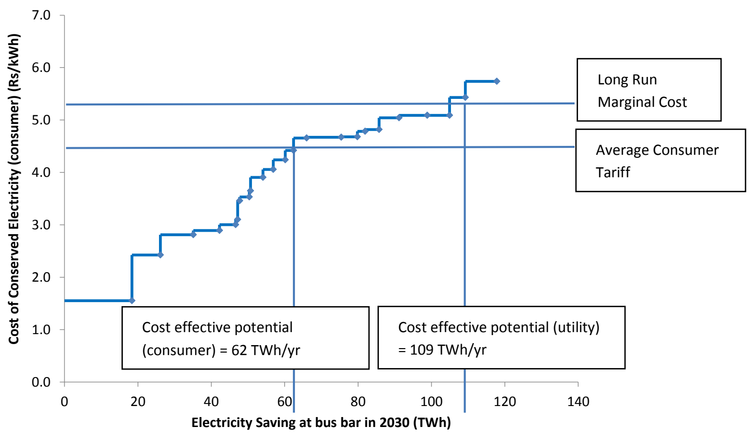


Figure 8: Efficiency Supply Curve in 2030 for Room ACs in India

The cost-effective saving potential from consumers' perspective is 62 TWh at bus-bar while the cost-effective saving potential from the utility perspective is found to be 109 TWh at bus-bar in 2030.

5.2 Peak Saving Potential

The following chart shows the peak demand from room ACs in 2020 and 2030. The chart also shows the peak saving potential in the form of wedges; each wedge refers to an efficiency improvement design option presented in section 3.1.

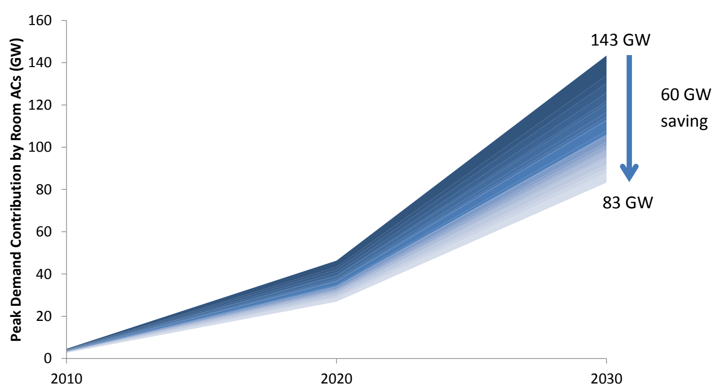


Figure 9: Peak Demand Contribution by room ACs and Peak Saving Potential

By 2030, enhancing the AC efficiency can save nearly 60 GW of peak demand at bus-bar. This is equivalent to saving nearly 120 power plants of 500 MW each. Note that power system has to be planned for meeting the total energy as well as peak demand. High seasonal or diurnal variation in demand makes inefficient use of the generation and transmission assets and therefore increases the total cost of system operation. Reduction in the peak demand lowers the power system investment and also improves the capacity factor of the existing power plants.

6 Conclusions

In this paper, we have showed the design options and estimated the incremental cost for enhancing efficiency of room air conditioners in India. Electricity consumption by room ACs is expected to increase from 8 TWh in 2010 to 239 TWh by 2030. Such growth would have significant impact on the Indian power sector and would require unprecedented construction of new power plants. We find that 40% of the energy consumed by room ACs could be saved cost-effectively by enhancing their efficiency. This translates to a potential energy saving of 118 TWh at bus-bar or a peak demand saving of 60 GW by

2030. This potential saving is equivalent to avoiding the construction of 120 new coal-fired power plants of 500 MW each. In order to realize this large cost-effective potential, a coordinated approach of market push (standards) and market pull (awards, labels, and incentives) is needed. Indian MEPS is one of the lowest in the world; therefore, the standards and labeling program in India need to be revised significantly. Given that the AC demand reduction is cost-effective from consumer as well as utility perspective, ratepayer funds can be used to undertake incentive programs. Such funds for ACs can be collected from high electricity consumption customers to ensure equity. Because the space cooling demand in India is temporally coincident across regions, the contribution of room ACs to the peak demand would be significant. Therefore, standards for making the room ACs demand response ready are recommended. It is also important to pursue efforts such as improved building design and cool rooms to reduce or postpone the AC demand. More research and analysis is required for assessing the use of climate specific space cooling technologies like modified evaporative ACs designed specifically for humid climates. For estimating the peak demand contribution and saving from ACs more accurately, daily and hourly variations in the space cooling demand (i.e. heat indices) should be considered. Therefore, an important future work emerging out of this analysis is developing a methodology for estimating the impact of space cooling demand on the power system more accurately. This analysis could be performed by introducing a random variable for local weather changes, and elementary load-flow analysis.

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TRANFORMING A RESIDENTIAL APPLIANCE MARKET

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Abstract

This report provides an evaluation of the impacts of the Energy Star Appliance Rebate Program in British Columbia, Canada. BC Hydro's Energy Star Appliance Rebate program is a multi-year energy acquisition and market transformation initiative that encourages its customers to purchase energy-efficient Energy Star appliances. The program objectives are to: (1) significantly impact market penetration of Energy Star appliances to increase market share and energy savings, and (2) drive future enhancements to energy efficiency legislation for household appliances. The purpose of this study is to conduct a process, impact and market evaluation of BC Hydro's Energy Star Appliance Rebate program.

Introduction

This report provides an evaluation of the impacts and effects of the Energy Star Appliance Rebate Program. BC Hydro's Energy Star Appliance Rebate program is a multi-year energy acquisition and market transformation initiative that encourages its customers to purchase energy-efficient Energy Star appliances. The program objectives are to: (1) significantly impact market penetration of Energy Star appliances to increase market share and energy savings, and (2) drive future enhancements to energy efficiency legislation for household appliances. The purpose of this study is to conduct a process, impact and market evaluation of BC Hydro's Energy Star Appliance Rebate program.

The Environmental Protection Agency introduced the Energy Star program as a voluntary initiative in 1992 (Brown, et al. 2000). The purpose of the program was to identify and promote energy-efficient products with the goal of reducing carbon dioxide emissions. The program began with computers, computer monitors and printers in 1992. Subsequent additions included: fax machines, copiers, residential heating and cooling equipment, thermostats, new homes, commercial buildings and exit signs in 1995; refrigerators, room air conditioners, clothes washers and dishwashers in 1996; windows in 1998; and screw-in CFLs in 1999. From January 2008 to May 2010, the BC Hydro Appliances Rebate Program provided rebates on Energy Star labelled clothes washers, refrigerators and freezers.

Literature Review

Market transformation programs create new challenges and opportunities for program evaluation. On the one hand, traditional evaluation techniques such as use of pre/post comparisons with treatment and control/comparison groups may not be possible if the treatment group is potentially the whole population. On the other hand, econometric techniques, such as the interrupted time-series model, can potentially deal with confounding market effects including free riders and spillover in a comprehensive and credible manner. The program evaluation literature on appliance markets includes both econometric and non-econometric studies. In this brief review, some of the peer-reviewed literature on market transformation in the residential sector is summarized.

The econometric studies use information on sales and drivers of sales to estimate the impact of program interventions on sales of energy-efficient products. Duke and Kammen (1999) found that accounting for the interaction between the demand response and production response for electronic ballasts increases the consumer benefit-cost ratio. Habart et al. (2004) found a significant impact of Energy Star promotion on sales of qualifying refrigerators and clothes washers. Horowitz (2001) found that coordinated national electronic ballast programs were more cost effective than local efforts. Horowitz and Haeri (1990) found that the cost of energy efficiency investments was fully capitalized in housing prices and that purchasing an energy-efficient house was cost effective. Jaffe and Stavins

(1995) found that insulation levels in new residential housing appropriately reflect energy prices. Tiedemann (2004) found that the China Green Lights program, which was closely modeled on the U.S. program, had statistically significant positive impacts on sales of more efficient lighting products and negative impacts on sales of less efficient lighting products. Tiedemann (2007) found that increases in energy prices and energy efficiency activities launched in the wake of the 2001 California energy crisis led to increased sales of Energy Star appliances. One reviewer commented that the following factors were important during the California energy crisis: they saw a four-fold increase in EE PGC-funds; were in the news all the time; there was a “panic” and rebates that were too juicy to pass by. Retailers sought to differentiate themselves by stocking more (and one even exclusively) E Star products. It was not just about prices and energy efficiency activities—there were many other reinforcing elements—social pressure, media, and the like that were adding significant impetus.

The non-econometric studies employ a variety of approaches. Nadel et al. (2003) provided a comprehensive overview of market transformation activities in the United States, and they found the beginnings of significant transformation in appliance markets. Titus and Feldman (2003) defined the analytical and data requirements for tracking the effectiveness of energy-efficient appliance programs, and they applied their model to the Wisconsin Focus on Energy’s CFL Program and to the Efficiency Vermont’s appliance program. Rosenberg (2003) used cross-section state data to estimate the determinants of Energy Star market share for the four major household appliances. Webber, Brown and Koomey (2000) provided a comprehensive set of both historical energy savings and forecast savings due to Energy Star. They explored the magnitude and allocation of Energy Star savings in detail, but they did not examine the determinants of sales. Meyers et al. (2003) estimated historical and forecast impacts of Energy Star sales on energy use and carbon emissions, and they estimated that Energy Star products saved 740 PJ of energy and 13 million tonnes of carbon emissions through 1999. Mauldin et al (2005) examined determinants of prices for Energy Star and non-Energy Star room air conditioners. Vine et al. (2010) developed a comprehensive framework for the evaluation of market effects in California. Their framework included six components: (1) prepare a scoping study: (2) analyze market conditions; (3) analyze market effects; (4) assess attribution; (5) estimate energy savings; and (6) assess sustainability. Using this framework, their study examined market transformation for three California programs, CFLs, residential new construction and high bay lighting.

Method

For this study, there were five main activities: (1) conduct a program review; (2) undertake a supply-side assessment; (3) undertake a demand-side assessment; (4) review price trends for Energy Star-qualifying and non-Energy Star-qualifying appliances; and (5) estimate energy and peak savings.

- **Program Review.** To conduct the program review and develop the program logic model, we reviewed program documents, interviewed BC Hydro program staff, and conducted a literature review focussing on recent studies and reports of residential appliances.
- **Supply-Side Assessment.** To undertake the supply-side assessment, we tabulated and examined relevant results of the annual in-store surveys of appliance stock behaviour in representative samples of retail sales establishments. The surveys have about 40 participants per year.
- **Demand-Side Assessment.** To undertake the demand-side assessment, we tabulated and examined relevant results of the quarterly Energy Star Tracker surveys. The surveys have about 700 participants per quarter.
- **Price Trends.** To review price trends for Energy Star and non-Energy Star appliances, we tabulated and examined relevant results from the annual in-store surveys.
- **Energy and Demand Savings.** To estimate demand and energy savings, we used the following algorithms:

  (1) ΔkW = Incremental units*unit energy savings,

(2) ΔkWh = Incremental units*unit peak savings.

The number of incremental units is based on an econometric model, and the unit energy savings are based on information on models available for sale from the in-store surveys.

Results

Program Review. At the time of program launch in 2008, a market analysis indicated that there were several barriers to market transformation including low awareness of Energy Star appliances among consumers, low availability of Energy Star product in stores, and high prices for Energy Star products. BC Hydro has employed a phased strategy to transform the household appliance market and acquire energy and peak savings. The program has successfully addressed these barriers through four main activities: information and promotions, sales tax exemption, financial incentives and legislative support for more stringent Minimum Energy Performance Standards.

Table 1 provides a program logic model focussing on input, output, purpose and goal statements for each of the four main activities. The program rationale was examined using this program logic model, which was developed from interviews with staff, a documents review and a literature review. This review and analysis confirmed that the basic program logic was valid. There were strong linkages among inputs, outputs, purposes and goal statements. Indicators for key components of the logic model were clear, well defined and measurable.

Table 1. BC Hydro Energy Star Appliance Rebate Program Logic Model

	Information and promotions	**Sales tax exemption**	**Financial incentives**	**Legislative support**
Inputs	Develop information and promotional materials	Provincial Sales Tax (7% PST) exemption for Energy Star clothes washers, refrigerators and freezers thru March 31, 2010	$50 (CAD) incentive for Energy Star fridges and clothes washers and $25 (CAD) incentive for Energy Star freezers thru March 31, 2010	Technical support for efficient appliance standards development
Outputs	Customer product awareness increased	First cost of Energy Star appliances reduced	First cost of Energy Star appliances reduced	Legislation and regulations in place
Purpose	Increased customer intent to purchase Energy Star appliances	Increased consumer purchases of Energy Star appliances	Increased consumer purchases of Energy Star appliances	Prevent backsliding in the residential appliance market
Goal	Significantly impact market penetration of Energy Star appliances to increase market share and energy savings of 4.9 GWh Drive energy efficiency legislation for household appliances			

Supply-side Assessment. In this section, we examine the supply side of the market for refrigerators, freezers and clothes washers. The surveyed retail stores averaged 35 refrigerator units on display. The product shares are as follows: bottom mount - 56%, top-mount - 26%, side by side - 19%. Table 2 shows the Energy Star share for refrigerators by type of store. The Energy Star share increased from 57% in 2009 to 78% in 2010.

Table 2. Energy Star Share of Refrigerators by Store Type

	Department store	Appliances/ furniture	Other	Total
2009	61%	46%	71%	57%
2010	84%	71%	78%	78%

The surveyed retail stores averaged 8 freezer units on display. The product shares are as follows: chest freezers - 61%; upright freezers - 39%. Table 3 shows the Energy Star share for freezers by type of store. The Energy Star share decreased from 48% in 2009 to 39% in 2010. The reason for this is not clear, but with a small sample size there may be a high level of variability.

Table 3. Energy Star Share of Freezers by Store Type

	Department store	Appliances/ furniture	Other	Total
2009	53%	25%	73%	48%
2010	43%	15%	60%	39%

The surveyed retail stores averaged 24 clothes washer units on display. The product shares are as follows: front load - 73%; top load - 27%. Table 4 shows the Energy Star share for clothes washers by type of store. The Energy Star share increased from 70% in 2009 to 79% in 2010.

Table 4. Energy Star Share of Clothes Washers Freezers by Store Type

	Department store	Appliances/ furniture	Other	Total
2009	72%	66%	75%	70%
2010	74%	81%	80%	79%

Demand-side Assessment. To determine unaided awareness of Energy Star, respondents were asked “Have you seen or heard of the Energy Star label?” Those who indicated “yes” were viewed as having unaided awareness of the Energy Star label. Those who responded “no” to this first question were asked “Please look at the Energy Star label: have you seen or heard of this label?” Those who responded “yes” were added to the unaided aware to determine aided awareness. Table 5 shows the results for Energy Star awareness for the period 2007:Q4 to 2010:Q2. Unaided awareness has increased substantially over the period surveyed, from 46% in 2007:Q4 to 68% in 2010:Q2. Total awareness has also increased, rising from 72% in 2007:Q4 to 85% in 2010:Q2.

Table 5. Energy Star Awareness

	Unaided (%)	Additional (%)	Total %
2007:Q4	46	26	72
2008:Q1	49	25	74
2008:Q2	50	26	76
2008:Q3	53	20	73
2008:Q4	61	23	74
2009:Q1	62	21	83
2009:Q2	62	19	81
2009:Q3	75	13	88
2009:Q4	70	16	86
2010:Q1	65	24	89
2010:Q2	68	17	85

Respondents who purchased various products over the 12 months before the survey were asked a series of questions about the label and about the product they purchased, but it should be noted that the sample sizes were relatively small, since in any given year, only a small share of customers purchase a new major appliance.

Table 6 shows the results for Energy Star recall for the period 2007:Q4 to 2010:Q2. For all three appliances, the share of Energy Star label recall increased over the period covered by the surveys. Energy Star label recall increased from 51% to 62% for refrigerators, from 45% to 54% for freezers, and from 58% to 65% for clothes washers.

Table 6. Energy Star Label Recall

	Refrigerators (%)	Freezers (%)	Clothes Washers (%)
2007:Q4	51	45	58
2008:Q1	40	41	41
2008:Q2	57	56	53
2008:Q3	56	48	45
2008:Q4	63	68	56
2009:Q1	68	58	61
2009:Q2	55	59	61
2009:Q3	57	59	66
2009:Q4	65	61	68
2010:Q1	66	54	66
2010:Q2	62	54	65

Respondents who saw the Energy Star label on the products they purchased were asked questions about the importance of the influence of the Energy Star label on their purchase decision. Table 7 shows the results of this enquiry. For all three appliances, the influence of the Energy Star label is quite high, but there is no particular trend in the share of respondents saying that the Energy Star label is very or somewhat important in the purchase decision. In other words, using 2007:Q4 as the baseline period, there is little apparent movement in the share of respondents indicating that the Energy Star label was very or somewhat influential in their choice of product.

Table 7. Energy Star Influence on Purchase (very/somewhat influential)

	Refrigerators (%)	Freezers (%)	Clothes Washers (%)
2007:Q4	86	90	86
2008:Q1	74	78	75
2008:Q2	81	95	78
2008:Q3	89	100	79
2008:Q4	93	91	83
2009:Q1	90	93	90
2009:Q2	88	86	88
2009:Q3	90	90	90
2009:Q4	86	90	90
2010:Q1	77	67	86
2010:Q2	85	95	80

Prices. Appliance price comparisons are complicated because prices are driven by a number of factors including volume, features, materials used as well as whether or not they are Energy Star compliant. Table 8 shows the prices for major appliances by Energy Star status for the 2009 in-store survey. This study suggests that the wedge between Energy Star and non-Energy Star appliances may be substantial, with Energy Star appliances being more expensive than non-Energy Star appliances.

Table 8. Energy Star and Non-Energy Star Prices, 2009

	Energy Star	Non-Energy Star	All appliances
Clothes washers	$1250	$767	$1105
Refrigerators	$1586	$1346	$1501
Upright freezers	$831	$488	$638
Chest freezers	$431	$356	$395

Table 9 shows the prices for major appliances by Energy Star status for the 2010 in-store survey. This study suggests that the wedge between Energy Star and non-Energy Star appliances may have widened for clothes washers and refrigerators but narrowed substantially for upright freezers and for chest freezers.

Table 9. Energy Star and Non-Energy Star Prices, 2010

	Energy Star	Non-Energy Star	All appliances
Clothes washers	$1266	$734	$1149
Refrigerators	$1646	$1219	$1589
Upright freezers	$635	$581	$611
Chest freezers	$344	$311	$331

Energy and Peak Savings. The energy and peak savings were estimated in several steps. First, unit energy savings were calculated for each appliance, using the information on the Energy Star labels. Second, the program impact on shipments of Energy Star appliances was estimated using an econometric model. Third, the results of the regression model were used to estimate the program impacts on appliance shipments. Fourth, engineering algorithms were used to estimate energy and peak impacts.

Information on kWh per cubic foot for Energy Star and non-Energy Star appliances and average volumes in cubic feet were obtained from the in-store survey.

Step 1. The following algorithm was used to estimate energy savings per unit for appliance j:

(3) Unit savings$_j$ = (ES kWh per cu ft$_j$ – Non-ES kWh per cu ft$_j$)* (Volume in cu ft$_j$)*(1 –cross effects$_j$).

The results are shown in Table 10. Unit savings for clothes washers were estimated to be 188.0 kWh per year. Unit savings for refrigerators were estimated to be 55.9 kWh per year. Unit savings for freezers were estimated to be 29.3 kWh per year.

Table 10. Appliance Unit Energy Savings

	ES (kWh per cubic ft)	Non-ES (kWh per cubic ft)	Volume (cubic ft)	Cross effects (%)	Savings (kWh per unit)
Clothes washers	48	95	3.9	-	188.0
Refrigerators	23	26	20.3	8.2	55.9
Freezer	39	42	10.0	2.4	29.3

Step 2. The following monthly econometric model for the period January 2003 to March 2010 was used to estimate the impact of the program on monthly appliance shipments:

(4) $Ship_m = \alpha + \beta Perm_m + \gamma Wage_m + \delta PSARP_m + \theta\, Q2_m + \lambda Q3_m + \eta Q4_m + \varepsilon_m$

where variables (and their sources) are as follows: Ship is shipments of ES qualifying refrigerators and clothes washers (from the Canadian Appliance Manufacturers Association). Perm is residential building permits (from BCStats[1]); wage is wage rate (from BCStats); PSARP is dummy variable for presence of program; Q2, Q3 and Q4 are quarterly dummy variables; ε is an error term; m indexes months.

Results are shown in Table 11. The regression results are good with an adjusted R-squared of 0.66, and all of the coefficients are significant at the 10% level. The key point is that realization on the program variable is 2,355 units per month compared to program incentives of 4,874 for clothes washers and refrigerators for a realization rate of 48.3%. We use this realization rate for freezers too, where we have no monthly shipments data.

Table 11. Regression Results for Refrigerators and Clothes Washers

Variable	Coefficient	Standard error
Constant	-18686*	9584
PSARP	2355***	824
Wage	28.2**	12.9
Building permits	0.0049***	0.0012
Q2	1045**	501
Q3	1582***	494
Q4	1374***	501
Adjusted R-squared	0.66	

One, two and three asterisks mean that the coefficient is statistically significant at the 10%, 5% or 1% level respectively.

Step 3. The following algorithm was used to estimate net units shipped for appliance j:

(5) Net $unit_j$ = Rebates per $month_j$*Net to gross ratio.

Results are shown in Table 12. As explained above, a common net-to-gross ratio of 0.483 is applied to the average number of rebates per month. The number of units attributable to program activities per month is 1,249 clothes washers, 1,106 refrigerators, and 155 freezers. It should be noted that regression models were also run separately for clothes washers and refrigerators. However, the project team decided to use the results of the pooled regression and apply the results to freezers because of the absence of freezer shipment data.

Table 12. Net Units per Month

	Rebates per month	Net to gross ratio	Net units per month
Clothes washers	2584	0.483	1249
Refrigerators	2290	0.483	1106
Freezers	320	0.483	155

Step 4. The following algorithm was used to estimate energy savings for appliance j:

(6) Energy $savings_j$ = Unit $savings_j$*Change in net number of $units_j$.

Results are shown in Table 13. For clothes washers, annual energy savings are 6.1 GWh and annual peak savings are 1.9 MW. For refrigerators, annual energy savings are 1.6 GWh and annual peak savings are 0.5 MW. For freezers, annual energy savings are 0.1 GWh and annual peak savings are 0.04 MW. It should be noted that the current residential appliance metering project will provide more accurate and recent information on peak savings in relation to energy savings.

[1] http://www.bcstats.gov.bc.ca/Home.aspx

Table 3. Energy and Peak Savings

	Savings (kWh per unit)	Change in net number of units	Energy (GWh per year)	Peak (MW per year?)
Clothes washers	188.0	32474	6.11	1.91
Refrigerators	55.9	28756	1.61	0.51
Freezers	29.3	4030	0.12	0.04
Total			7.84	2.49

Conclusions

Program Design and Implementation. The BC Hydro Residential Energy Star Appliance Program achieved considerable success in building product awareness, and purchase behaviour for Energy Star qualifying appliances. Total awareness increased, rising from 72% in 2007:Q4 to 85% in 2010:Q2 and for all three appliances, the share of Energy Star label recall increased over the period covered by the surveys. The program is cost effective (Total Resource Cost greater than 1.0 and Ratepayer Impact Measure greater than 0.8) and has evolved over time in response to changes in market conditions, with the current program focusing on the highest tier of energy efficient appliances.

Program Energy, Peak and Price Impacts. Engineering algorithms informed by customer survey data and by the showroom stock study were used to estimate program impacts. Evaluated energy savings were 7.8 GWh compared to business plan forecast energy savings of 11.6 GWh, while evaluated peak savings were 2.5 MW. The price wedge between Energy Star qualifying and non-Energy Star qualifying appliances may be substantial, but it is not clear how much of the price wedge is due to energy-efficient features and how much is due to other factors.

Evaluation Methods. Evaluations of residential appliance programs usually rely heavily on self-report information to deal with attribution including the issue of free riders. However, in market transformation programs, the evaluation issues are relatively subtle and may require more sophisticated methods. In this study, econometric modelling of appliance demand has been used to estimate program impacts. This may be a fruitful approach for the future evaluation of residential appliance programs.

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Costs and Benefits of Energy Efficiency Improvement in Ceiling Fans

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Abstract

Ceiling fans contribute significantly to residential electricity consumption, especially in developing countries with warm climates. The paper provides analysis of costs and benefits of several options to improve the efficiency of ceiling fans to assess the global potential for electricity savings and green house gas (GHG) emission reductions. Ceiling fan efficiency can be cost-effectively improved by at least 50% using commercially available technology. If these efficiency improvements are implemented in all ceiling fans sold by 2020, 70 terawatt hours per year could be saved and 25 million metric tons of carbon dioxide equivalent (CO_2-e) emissions per year could be avoided, globally. We assess how policies and programs such as standards, labels, and financial incentives can be used to accelerate the adoption of efficient ceiling fans in order to realize potential savings.

Introduction

This report presents the results of an analysis of ceiling fan efficiency, prepared in support of the Super-efficient Equipment and Appliance Deployment (SEAD) initiative.[1] SEAD aims to transform the global market through increasing availability of efficient equipment and appliances. The objective of this analysis is to provide the background technical information necessary to improve the efficiency of ceiling fans and to provide a foundation for the voluntary market transformation activities of SEAD participating countries.

Ceiling fans contribute significantly to residential electricity consumption in warm climates and especially in developing countries. For example, in India, ceiling fans alone accounted for approximately 6% of residential energy use in 2000. This figure is expected to grow to 9% in 2020 [1], an increase that is equivalent to the energy output of 15 mid-sized power plants.[2] In addition, ceiling fan ownership rates have been shown to significantly increase in low-income Indian households as income levels increase [1]. Although ceiling fan standards and labeling programs are specified for every major economy in the world, these programs only discourage the use of highly inefficient fans [8]. In developed countries and countries with milder climates, a smaller fraction of electricity consumption is attributable to ceiling fans. Nevertheless, ceiling fans account for as much as 5% of residential electricity use in the U.S., although this varies greatly by region [12]. Even in those areas where they do not constitute a significant fraction of electricity demand, ceiling fans can reduce energy consumption by reducing the use of other cooling devices. Fans are well known to be a cost-effective option for reducing the electricity demand of air conditioners [13], [14]. Air conditioners are responsible for approximately 16% of residential electricity consumption in the U.S. In addition, ceiling fans are essential features in passive cooling systems aimed at achieving energy-efficient thermal comfort [15], [16].

This study assesses the potential for global ceiling fan energy-efficiency improvement. We analyze the cost-effectiveness of ceiling fan efficiency improvements while estimating the global potential for both energy consumption and CO_2-e emission reductions. We utilize the Bottom-Up Energy Analysis System

[1] An initiative of the Clean Energy Ministerial (CEM) and a task within the International Partnership for Energy Efficiency Cooperation (IPEEC), SEAD seeks to engage governments and the private sector to transform the global market for energy-efficient equipment and appliances. As of October 2012, the governments participating in SEAD are: Australia, Brazil, Canada, the European Commission, France, Germany, India, Japan, Korea, Mexico, Russia, South Africa, Sweden, the United Arab Emirates, the United Kingdom, and the United States. More information on SEAD is available from its website at http://www.superefficient.org/ .

[2] For this estimate we assume an increase in BAU power consumption of ~20TWh, as outlined in the section titled " Energy Savings Potential". We also conservatively estimate that one-tenth of ceiling fans are used during the peak hour and that a mid-sized power plant has a 500-megawatt capacity and runs at 70% efficiency (as described in [11]). However, currently installed power plants in India have a much lower average efficiency [1].

(BUENAS) to make these estimates [11]. First we present a technological economic analysis of fan efficiency improvement options followed by global energy savings estimates. Finally we discuss implications for design of market transformation programs, and conclude the paper.

Techno-Economic Assessment of Efficiency Improvement Options in Ceiling Fans

Ceiling fan energy performance is typically measured in units of meters cubed per minute per Watt (m^3/min/W). This represents the ratio of air delivery to power input. The term "efficiency" is commonly used to represent the ratio of mechanical-output to electrical-input power. In this paper, we follow the example of earlier studies [17]. The term "efficacy" refers to fan performance, while the term "efficiency" is used as a general performance descriptor and when discussing the performance of motors.

Note: In Europe and India the term "Service Value" is used to refer to efficacy.

Table 1. Summary of characteristics used in various standards and labeling programs

Country	Agency	Standard/ Label Type		Speed	Size category	Rating type
India	BIS	Standard	Voluntary		Yes	Specifies minimum efficacy for various fan sizes
India	BEE	Label	Voluntary		Only 1200 mm	Assigns star ratings to fans meeting minimum efficacy requirements
China	NDRC, AQSIQ	Standard	Mandatory		Yes	Assigns ratings based on efficacy, to fans classified by size
U.S.	EPA	Label	Voluntary	Yes		Specifies minimum efficacy for fans classified by operating speed
Europe	Ecodesign Forum	Standard	Mandatory		Yes	Specifies a minimum efficacy for various fan sizes

Standards and labeling programs for ceiling fans are typically designed to ensure a specified level of efficacy. Specifications include sub-categories that are classified by characteristics such as fan size, operating speed, or airflow. Fans have higher efficacy at lower speeds meaning standards and labeling programs categorize fans by operating speed [17]. Fan efficacy can be increased through increasing blade length because power consumption decreases with as blade length increases assuming constant airflow. Accordingly, some programs categorize fan standards and labels by fan size or sweep. Table 2 summarizes fan standards and labeling frameworks in various countries. In the U.S., the ENERGY STAR program specifies minimum ceiling fan efficacy rankings for three different airflow levels [3]. Similarly, the Indian standard IS-374 defines minimum efficacy levels for five different ceiling fan size categories [10]. In addition to this, the Indian Bureau of Energy Efficiency (BEE) maintains a star rating system based on fan efficacy [4]. However, the Indian star rating system is applicable to only one size of fan (1200 mm) and does not vary by fan speed.

Efficiency Improvement Options for Ceiling Fan Systems

The ceiling fan system consists of multiple components that together determine the fan's overall energy consumption. We focus on engineering improvements that are easily quantifiable such as changes to fan motors and blades that improve ceiling fan efficiency.

Fan Motors

Historically ceiling fans have utilized AC induction motors because these motors are durable, easy-to-construct, and relatively inexpensive to manufacture. Permanent split-capacitor motors are prevalent in ceiling fans manufactured in India, and shaded-pole motors are prevalent in ceiling fans manufactured in the U.S. and Europe [20]. However, these AC induction fan motors are relatively inefficient because of the slip[3] associated with single-phase induction motors. Brushless DC (BLDC) motors have become increasingly common in appliances in recent decades due to developments in electronic commutation and the availability of inexpensive and high-performing magnetic materials [21]. Such motors are more efficient than brushed DC motors because they do not have the friction loss associated with mechanical commutation. Induction motors are inefficient because their rotors do not rotate synchronously with the magnetic field that induces rotor motion which results in slip. BLDC motors alleviate these issues because the rotor moves synchronously with the rotating AC magnetic field produced by electronic commutation. For instance, a 75 W BLDC motor has been estimated to have an efficiency of up to about 90% whereas the average new 75-W AC induction motor has an efficiency of around 75% [21]. Table 2 shows these efficiencies along with those of other 75-W motors.

Multiple engineering studies have estimated the potential for reducing energy consumption through the use of BLDC motors. One experimental Taiwanese study shows that the energy consumption of a ceiling fan with a BLDC motor is about 50% that of a fan with a split-phase induction motor [22]. An experimental study from Australia shows that BLDC motors decreases ceiling fan energy consumption by a factor of three at low speeds and a factor of two at high speeds [23]. Industry experts indicate that using a BLDC motor can reduce energy consumption by an estimated 60% in the U.S. and 50% in India [24],[20]. In addition to the potential energy efficiency improvements achieved with BLDC motors, some fans in India incorporate a combination of elements that affect AC induction motor efficiency. These fans consume significantly less energy than normal [20],[25]. At high speeds, these fans can reduce power consumption from 70-75 W to about 45-50 W. The elements that [20] cites as influencing AC induction motor efficiency in these fans are increased amount of “active” material (such as lamination steel and copper), reduced air gap between stator and rotor and incorporation of standard-grade aluminum for die-cast rotors.

Table 2. Efficiency data for various 75-W motor types in the U.S.

Motor type	**Efficiency**
NovaTorque[4]	90%
Practical Limits BLDC[6]	87%
Practical Limits AC Induction	84%
Average New Production	75%
Average Installed Base	60%

Source: Desroches & Garbesi 2011 [21]

Fan Blades

Improving fan blade design has been shown to have significant influence on fan efficiency. Efficiency improvements have been achieved by multiple approaches. Incorporation of aerodynamic attachments for conventional blades [26]; a decrease in the angle of attack through the use of twisted, tapered (TT) blades [27]; and use of TT blades with an air foil [28]. We focus on the last of these options due to wide use of this type of blade and the potentially large energy savings that are associated with this design.

[3] The slip is the difference between the speed of the rotor and the magnetic field in an AC induction motor.

[4] The company Novatorque has incorporated technical improvements to push efficiency further beyond the so-called “practical limits” of a BLDC motor.

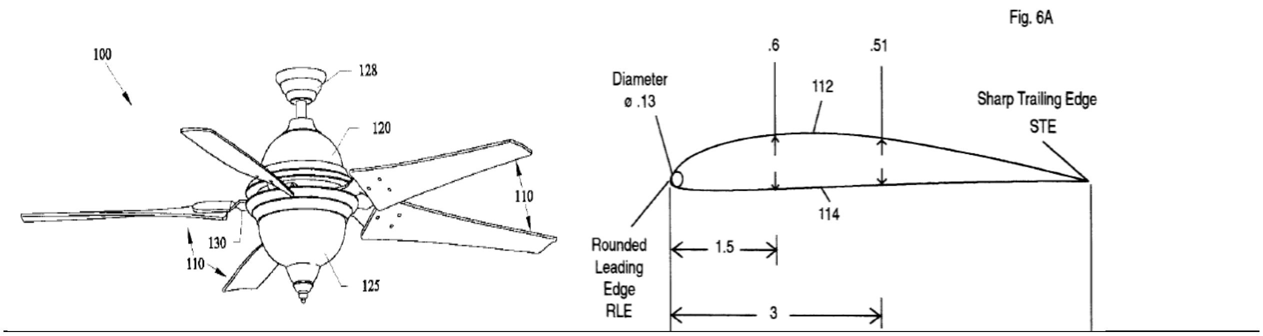

Figure 1. Design drawings from a patent for a ceiling fan with twisted, tapered blades with an airfoil. [5] Source: Parker et al. [40]

TT blades with an airfoil increase efficiency by reducing energy lost to turbulence and flow-separation as shown in Figure 1 [29]. Optimal blade design requires a balance between multiple objectives including maximization of air speed, uniform air speed along the fan radius, and maximization of airflow coverage. A test of one such patented blade design indicates that the subject invention has an efficacy 86%-111% higher than that of a conventional flat blade, indicating remarkable potential for energy-efficiency improvements from changes in fan blade design [30]. These blades can also be used to reduce motor size and cost, and the resulting device will still outperform a conventional fan [30]. Some efficient blade designs have been adapted for aesthetic purposes to appear like traditional blades from the bottom-side while being aerodynamic on the top-side, thus improving efficiency 10%- 26% when compared to conventional designs [31]. The blade has been designed to meet a market preference by some consumers for energy-efficient fans with a traditional appearance.

Fan Efficiency Improvement Opportunities: Empirical Evidence from the US Market

Figure 2 shows ENERGY STAR market data for qualifying fans being sold in the U.S. and Canada [3]. The information regarding motor and blade type was obtained from product catalogs and phone calls with representatives from ceiling fan manufacturers producing fans with the highest efficacies. These companies include Monte Carlo, Fanimation, Regency, and Emerson [32]. The data in the figures are comparable to the performance of the most efficient fans being introduced in U.S. and Canadian markets. For instance, the Emerson Midway Eco fan is advertised as having a 75% reduction in energy consumption due to the Emerson EcoMotor TM [9].

[5] We note that most fans sold in India have 3 blades as opposed to the 5 pictured here. However, to be consistent with the patent filed by Parker (2003), we have pictured the 5 bladed design from the patent. The blade improvements will be similar for a fan with 3 blades.

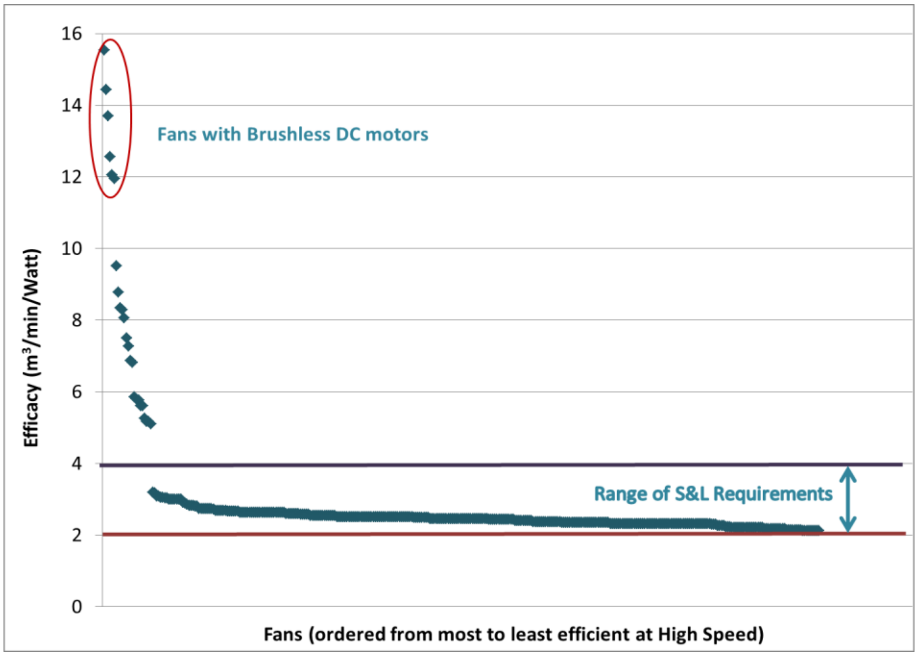

Figure 2. Efficacies for ENERGY STAR ceiling fans (fan only, without lights) at high speed[6]

Source: ENERGY STAR [33]

The figure shows that fans with BLDC motors have far higher efficacies than the current ENERGY STAR high-speed standard requires (2 m^3/min/W). This data indicates that engineering improvements, such as those previously discussed, can be used for purposes other than increasing efficacy. Other purposes include reducing motor size or material quality to reduce manufacturing costs in the absence of policy intervention to improve efficiency. To the authors' knowledge, there are no fans with BLDC motors in these figures other than those highlighted, although this is unconfirmed as we were not able to contact every fan manufacturer.

Technical and Economic Analysis of Efficiency Improvement Options

Here we estimate the costs of efficiency improvement of ceiling fans using the options previously described. We estimate the cost of conserved electricity (CCE) to assess the cost-effectiveness of these efficiency improvements. Due to data constraints, we only cite costs from a few countries while estimating the CCE.

Fan Motors

Based on data collected from industry experts we estimate the incremental cost of efficiency improvements of motors typically used in ceiling fans. We consider two types of efficiency improvement options. First, given that BLDC motors are significantly more efficient than induction motors, we estimate the incremental cost of BLDC motors of the same size and performance specifications over the typical induction motor. Second, we consider the cost of improving the efficiency of the induction motor itself, where the efficiency improvements are smaller and less costly compared to those achieved by a BLDC motor. BLDC motors are typically more expensive when compared to induction motors primarily because of the extra cost of the controller. Note that induction motors and BLDC motors have similar materials costs (excluding the BLDC motor controller). This is primarily because the extra cost of permanent magnets in a BLDC motor is compensated by reduction in costs due to less copper and steel (See [36] and [21] for a detailed discussion). Desroches & Garbesi find that that the global cost of materials for a 750-W (note that fan motors are typically much smaller, < 75W) induction motor is about US$43.80, and, for a BLDC motor, the materials cost ranges from US$24.20 to US$36.74, as of 2011 [21]. This indicates

[6] In 2010 and 2011, the market penetration of ENERGY STAR qualified ceiling fans was 18% and 13%, respectively [34] [35].

that the *materials* cost of a smaller BLDC motor, such as would be used in ceiling fans, should also range from a little less than to about equal to that of a comparable AC induction motor. Therefore, the incremental cost of the BLDC motor over an induction motor is essentially the cost of the controller. A BLDC motor controller is estimated to have a manufacturing cost between INR300-700 in India [20], [25]. The same controller would cost between US$3.2 to US$22.5 in the US [36]. We assume the incremental cost of a BLDC motor that replaces a typical ceiling fan induction motor of 75 W to be approximately US$10.50 for the purposes of this report.

Fan Blades

The cost of manufacturing efficient ceiling fan blades in the U.S. is estimated to be about US$2.25, versus US$0.25 per conventional flat blade [31], [30]. The incremental cost of manufacturing an efficient blade versus a conventional blade in India is about INR60 for 3 blades i.e. US$0.36/blade [20]. Although these appear to be significant cost increases for these components, they are not very large (~5%) compared to the total retail price of a ceiling fan. An important point to mention in the case of efficiency improvement through blade design is that blade design and manufacturing are driven by aesthetic considerations rather than just efficiency. This is also reflected in *divergent* estimates of the costs of manufacturing depending on the design, material, manufacturing, and treatment/finishing processes. The significance of aesthetic considerations in blade manufacture implies that *mandating* more efficient blades through minimum energy performance standards (MEPS) is not likely to be a practical or desirable option. However, given that some fans may be designed to meet energy efficiency policy specifications by using more efficient blades, it is still useful to estimate the costs of efficiency improvement through more efficient blades, particularly for labeling and incentive programs. Table 3 reports these costs in dollar terms along with average numbers, which are used as the input for the cost effectiveness calculation.

Table 3. Summary of reported manufacturing costs in dollars of efficiency improvement options[7]

Efficiency Improvement Option	**India**		**US**		Average($)
	[20]	[25]	[36]	[31]	
Improved AC Induction Motor	$1.09	$1.82			$1.5
BLDC Motor	$5.45	$10.91	$3.2-$22.5		$10.5
Efficient Blades	$1.09			$6.00	$3.5

Cost of Conserved Electricity

This section presents the CCE in India for motor and blade improvements described above, using the efficiency assumptions discussed earlier along with corresponding cost assumptions. Two kinds of CCEs are calculated as follows: the manufacturing cost of conserved electricity (CCE_m) which considers the incremental cost of the higher efficiency fan to the manufacturer and the cost to the consumer of conserved electricity (CCE_c) which considers the incremental cost of the higher efficiency model to the consumer. The former metric (CCE_m) is lower than the latter (CCE_c) as it does not include markups or taxes. Therefore, CCE_m can be used to measure the cost-effectiveness of a market transformation program, such as an upstream incentive program, while CCE_c can be used to measure the cost effectiveness of a standards program, or a downstream incentive program.

[7] In converting from a per-blade to a total incremental cost we assume the fan has 3 blades.

Table 4. Cost of conserved electricity for various efficiency improvement options in India[8]

Efficiency Improvement Option[9]	Average Power Savings (W)	% Reduction from baseline power	Average incremental manufacturing cost($)	CCE_m ($/kWh)	CCE_c ($/kWh)
Improved AC Induction Motor (A)	25	36%	$1.5	$0.003	$0.005
BLDC Motor (B)	35	50%	$10.5	$0.014	$0.027
Efficient Blades (C)	10	15%	$3.5	$0.015	$0.031
A+C	32	45%	$5.0	$0.007	$0.014
B+C	40	57%	$14.0	$0.016	$0.032

Assumptions: Lifetime=10 years; hours of use per day = 8.7; discount rate = 7.6%; multiplier for markup and taxes = 2.0

Shown above, improved AC induction motors are the most cost effective single option, followed by BLDC motors. We also note that our cost and efficiency assumptions (and resulting CCE estimates) regarding efficiency improvement using more efficient blades are *conservative* and may very well be lower than those shown. This can be attributed to using cost and efficiency estimates for more efficient blades with a traditional appearance as discussed earlier rather than the most efficient blades [31]. Also, data on blades indicated *divergent* estimates of the costs of manufacturing depending on design, material, manufacturing, and treatment/finishing processes, which varied due to aesthetic considerations. Given the globally traded nature, maturity, and high contribution of material costs to the total costs of the efficiency technologies considered, we argue that cost estimates based on the data in India and US are likely to be a reasonable approximation of the costs in other regions.

Energy Savings Potential

We used the Bottom-Up Energy Analysis System[10] (BUENAS) to estimate the potential global energy and CO_2 emission savings from accelerated implementation of the engineering developments for ceiling fans described earlier. A detailed description of the methodology is available in [11] and [38]. This version of BUENAS covers thirteen major economies, representing 80% of the world's total energy consumption. Our objective is to provide an approximate estimate for the potential savings from accelerated adoption of efficient fans. Precise estimates of the saving potential in each of the economies covered will require significant further work in order to provide a more robust empirical basis for the assumptions used. Note that we have more robust data on India, China, and the US compared to other countries and hence the estimates of saving potential for these countries are likely to be more accurate than for the others.

Data and Methodology

BUENAS is an end-use energy forecasting model designed to provide a detailed assessment of the potential for energy savings and GHG emissions reductions from energy-efficiency standards and labeling programs worldwide (see [38] for a detailed description of the model). The model is "bottom-up" in that it calculates energy demand based on input data for individual appliance products. BUENAS is composed of three modules. The first calculates the number of appliances per household (diffusion) in a country at a given point in time, primarily based on an empirical relationship observed between appliance ownership and macroeconomic household variables such as household income. The second module

[8] We have assumed a 100% markup in estimating costs to the consumer in line with [25]. Lifetime and hours of use assumptions are in line with [37].

[9] Efficiency improvement options from single components (A, B, C) are presented first followed by efficiency improvement options from combining two options (A+C and B+C). The options are subsequently ordered by increasing cost of conserved energy. Also option C, efficient blades can be used with both BLDC and AC motors. While BLDC motors and AC motors are widely available, efficient blades may be proprietary designs, and also carry associated aesthetic tradeoffs.

[10] http://www.superefficient.org/en/Products/BUENAS.aspx

estimates energy consumption and efficiency improvements at the appliance level. The third module is a stock turnover module that calculates the sales of appliances every year based on retirement of old units and increased penetration of appliances in households. This module combines the sales in every year with unit energy consumption (UEC) to estimate the total stock energy consumption. The difference in stock energy consumption between a Business As Usual (BAU) and an efficiency case equals the savings. Energy savings are then converted into CO_2 equivalent emission mitigation according to the power generation mix from each country.

Results

This section presents the BUENAS results in terms of stock energy consumption and global potential energy savings. BUENAS also provides CO_2 emission mitigation potential calculated using country-specific carbon factors [11].

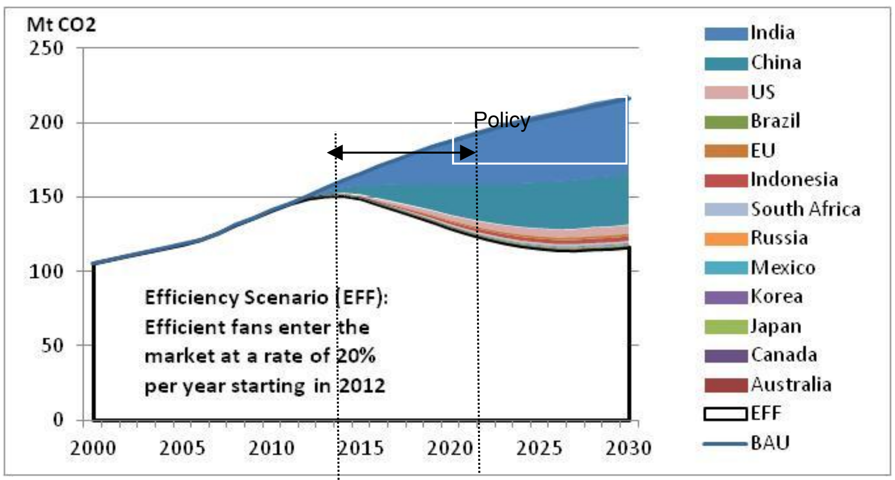

Figure 3. Potential CO_2 emissions reductions resulting from introduction of efficient fans, 2000-2030

Efficiency Scenario

In the efficiency scenario, efficient fans with BLDC motors gradually enter the market, gaining 20% of market share starting in 2012. The market reaches saturation in 2017 when 100% of fans sold are assumed to be efficient. The unit energy consumption (UEC) for efficient fans is assumed to be constant throughout the forecast period. We evaluate energy savings potentials in 2016, 2020, and 2030. Table 5 shows the results of the energy savings potential analysis, and Figure 3 shows the corresponding CO_2 emission results. India represents almost half of the potential electricity savings and CO_2 emission mitigation potential in the economies covered in this analysis.

Table 5. Annual and cumulative energy savings forecasts

	Annual Electricity Savings (TWh)			**Cumulative Electricity Savings (TWh)**		
Year	2016	2020	2030	2012-2016	2012-2020	2012-2030
Australia	0.05	0.12	0.21	0.12	0.50	2.31
Brazil	1.43	3.35	6.09	3.29	13.83	65.41
Canada	0.05	0.11	0.19	0.11	0.46	2.08
China	9.01	20.68	35.77	21.02	86.50	396.59
EU	0.48	1.08	1.76	1.14	4.59	20.22
India	14.17	33.54	62.38	32.52	137.91	660.60
Indonesia	1.12	2.63	4.81	2.59	10.88	51.51
Japan	0.24	0.54	0.84	0.56	2.27	9.90
Korea	0.11	0.26	0.44	0.26	1.07	4.91
Mexico	0.41	0.93	1.53	0.96	3.90	17.43
Russia	0.15	0.34	0.52	0.37	1.46	6.19
South Africa	0.17	0.40	0.65	0.40	1.67	7.46
U.S.	2.43	5.65	9.86	5.61	23.47	108.57
Total	**29.82**	**69.62**	**125.05**	**68.94**	**288.51**	**1353.19**

Realizing Cost-Effective Efficiency Improvements: Lessons for Market Transformation Programs

As discussed earlier in this report, there are several cost-effective options for improvement of ceiling-fan efficiency that would reduce fan energy consumption by more than 50%. Although highly efficient fans that incorporate most of the efficiency improvement options discussed in this paper are commercially available in certain countries (e.g., the U.S.), they constitute a very small percentage of sales. In some countries (e.g., India), fans with BLDC motors and efficient blades are not currently commercially available. Several barriers, including high purchase price and lack of information (e.g., lack of labels that recognize highly efficient performance), have been identified that contribute to the limited adoption of highly efficient fans [4]. In this section we discuss some broad insights for energy efficiency market transformation programs based on the earlier discussion.

General Insights

Some of the insights that can be drawn from the preceding discussion apply across various types of market transformation programs and policies. We discuss some such general insights with respect to key fan characteristics such as fan size and speed, and with respect to blade design.

It is important for market transformation programs to classify fans by size and take into account the effect of fan speed on efficacy. First-and-foremost, size categories are important in market transformation programs to preclude the possibility that simply increasing blade length, without necessarily delivering better service, could circumvent a policy based merely on efficacy. For instance, although airflow increases with larger blades the amount of cooling felt by the user may not. This is because the service delivered to the final user (in this case, cooling) depends not on the total volume of air moved, but also on the velocity of the air[11]. If market transformation policies classify fans by size, fan manufacturers will not be able to simply install longer blades to improve efficacy nominally without competing with other manufacturers in a separate size category or improving the service delivered to the final user. Second, operating speed is also an important criterion in designing market transformation programs because efficacy varies inversely with increasing fan speed [39]. This effect can be addressed either by using standard speed or minimum airflow in the test procedure for the program, such as in India's standard and labeling programs, or by changing the efficacy requirement at various speeds, such as in the ENERGY

[11]The coefficient of convective heat transfer off the human body depends on the velocity of the air [75].

STAR program. It should be noted that the testing burden would be lower in the first case, with a tradeoff on the accuracy of the test procedure at various speeds.

The literature discussed earlier indicates that there is remarkable potential for energy-efficiency improvements from changes in fan blade design. We also find that blade design improvements have greater efficacy/power consumption savings impact at higher speeds. This implies that market transformation programs in economies with hotter climates and higher average airflows (e.g. India) will benefit proportionally more from blade design improvements than economies where average airflows tend to be lower. (e.g. the US). For example, the most efficient blade designs discussed in the literature will improve efficacy by 86% at lower speeds (airflows), versus 111% at higher speeds (airflows) compared with conventional blade designs [30].

Standards and Labeling Programs

Efficiency levels specified by standards and labeling programs are far below what can be achieved by implementing cost-effective energy-efficiency options in ceiling fans (see Figure 4). For example, as seen from data on the efficacy of fans meeting the US ENERGY STAR requirements, fans using BLDC motors and efficient blades are significantly more efficient (with efficacy as high as 15 $\frac{m^3}{min}/W$) compared to efficiency requirement for qualifying for ENERGY STAR (efficacy of 2.1-4.2 $\frac{m^3}{min}/W$). Furthermore, the Indian Bureau of Energy Efficiency (BEE) voluntary star rating program for fans only covered 2% of the Indian market and only 18% of fans (without a light kit) on the US ceiling fan market were compliant with ENERGY STAR, indicating significant room for efficiency improvement [25], [3].

The standards and labels levels for BEE's star rating program in India are presented in Figure 13. These efficacy levels are tested under different conditions (notably airflow requirements/speeds) than standards and labels in the US, Europe and China so they cannot be directly compared against each other without accounting for this.[12] However, the improvements in efficacy discussed in this report are applicable across the range of commonly encountered airflows. This means that these improvements will offer significant energy savings of a similar order of magnitude regardless of airflow or test procedure alignment. For comparison, the US ENERGY STAR label has an efficacy requirement of 4.2 (m^3/min/W) at low speeds and 2.1 (m^3/min/W) at high speeds while the lowest standard for efficacy in China varies by fan size from 3.47 (m^3/min/W) for 1800 mm fans to 2.75 (m^3/min/W) for 900 mm fans [3], [5]. Figure 13 makes clear the significant potential for improvement in fan efficacy through increases in specified standards and labels.

The highest efficacy level recognized by labels in several countries is significantly lower than what can be achieved by adopting cost effective efficiency options. Hence current efficacy label levels need to be revised significantly to encourage deeper penetration of efficient ceiling fans at the top of the market with efficacies achievable using BLDC motors and efficient blades that are already on the market in the US, and that are cost-effective in other countries. The low penetration level of efficient ceiling fans in both India and the US seems to indicate the presence of barriers to efficiency other than information, such as first cost, that may not be able to be addressed within a standards and labeling framework.

[12] See [39] for a discussion of the effect of fan speed and motor speed on efficacy. Increasing airflow from 5000 CFM (the US high speed) to 7415 CFM (i.e.210 m^3/min, the minimum airflow for star rated fans in India), i.e. A 48% increase will yield a decrease in efficacy of at most 35%.

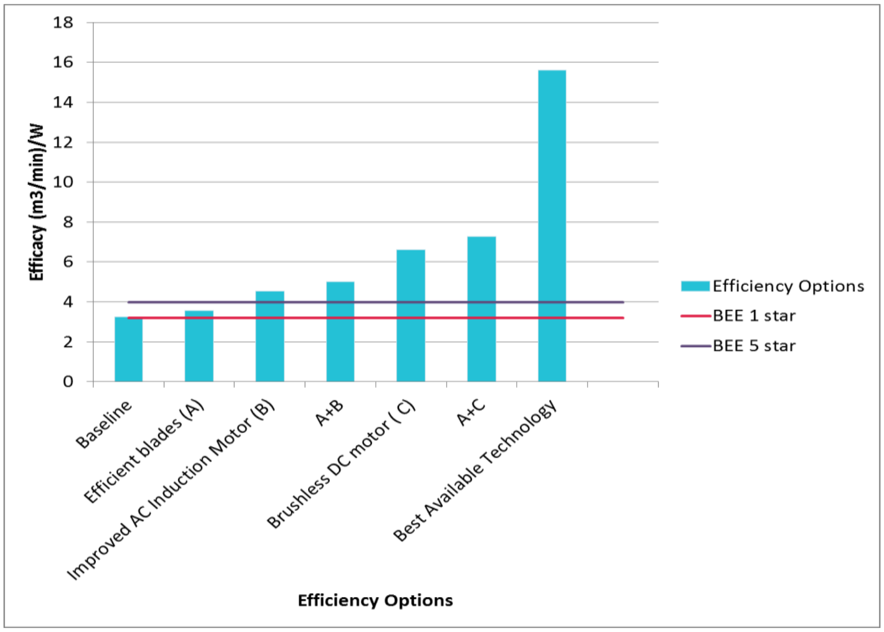

Figure 4. BEE (India) star labels compared to estimates of potential ceiling fan efficacy[13]

Incentive Programs

Incentive programs for efficient fans could accelerate the penetration of superefficient fans for the following reasons. First, adoption of cost-effective efficient appliances is often hindered by high first cost, e.g. as discussed in [6]. In emerging economies, consumers are highly sensitive to high first costs [4]. Second, due to the importance of aesthetics discussed earlier, it is not practical or desirable to mandate efficiency improvement from blade design through MEPS. However, the full existing potential from more efficient blades, as well as from BLDC motors, could be exploited through incentive programs for superefficient fans. Such programs could cost effectively target efficacies of up to 15 $\frac{m^3}{min}/W$, as discussed earlier. There are several examples of financial incentive programs that lower the first cost of cost-effective energy efficient appliances and equipment to accelerate their adoption. However, despite the large saving potential, financial incentive programs to promote the adoption of highly efficient fans are not common.

Conclusions

This paper presents an analysis of the potential for improvement of ceiling fan components to reduce global energy consumption and GHG emissions. Improved blade design and AC induction motor materials, and the increased use of BLDC motors, are identified as cost effective options to improve the efficiency of ceiling fans. Adaptation of these technologies could provide ceiling fan power consumption savings of more than 50%. Out of the several types of policies typically used to accelerate adoption of efficient products (e.g., awards, incentives, and standards and labeling programs), standards and labeling programs are most commonly used to accelerate the market penetration of efficient fans.

Efficacy levels are tested under different conditions (notably airflow requirements/speeds) in various countries so they cannot be directly compared against each other without accounting for this fact. Nevertheless, the improvements in efficacy discussed in this report are applicable across the range of commonly encountered airflows. Meaning these improvements will offer significant energy savings of a similar order of magnitude regardless of airflow or test procedure alignment.

[13] Note: The baseline efficacy value is based on the average values reported as 'National Player's Models' presented in (Garg & Jose 2009). Incremental improvements correspond to those presented earlier. The efficacy level of the best available fan corresponds to the fan with the highest efficacy in Figure 8.

The highest efficacy level required by standards and labeling programs in several countries is significantly lower than what can be achieved by adopting the cost effective efficiency improvement options discussed here. Hence current efficacy label levels need to be revised significantly to encourage deeper penetration of efficient ceiling fans at the top of the market.

The low penetration level of efficient ceiling fans in both India and the US, even with labeling programs in place,[14] seem to indicate the presence of barriers. These barriers to efficiency, in addition to information, such as first cost, may not be able to be addressed fully within a standards and labeling framework, particularly in emerging economies with price sensitive consumers. However, despite the large saving potential, financial incentive programs that promote the adoption of highly efficient fans by removing the first cost barrier are not common.

One notable example under development is the Super-Efficient Equipment Program (SEEP) in India where financial incentives will be provided to fan manufacturers to produce and sell highly efficient fans; fans that consume less than half of the energy consumed by fans typically sold on the Indian market [4]. Even if the entire incremental cost of the highly efficient fans is covered by the financial incentives, the cost of the conserved electricity for efficiency improvements over 50% is just 0.7 rupees per kWh (US$0.014/kWh) which is about one sixth of the cost of supplying electricity in India [6]. SEEP or a similar upstream incentive program for ceiling fans would be cost-effective even assuming higher costs and lower hours of use as discussed earlier. Therefore there remains significant scope for improved policy design and implementation for aggressive and cost effective ceiling fan efficiency improvements.

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[14] BEE's voluntary star rating program for fans only covered 2% of the Indian market, while only 18% of the fans(without a light kit) on the US ceiling fan market were compliant with ENERGY STAR (PWC, 2012, and EPA 2011) indicating significant room for efficiency improvement.

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Efficiency 2.1 – New media for best informed consumers regarding sustainable and energy efficient products

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Abstract

The main objective of this initiative – co-funded by the EU programme Intelligent Energy Europe Programme of the European Union and conducted by a consortium of 12 partners – is to support consumers in their purchase decisions by providing up-to-date information about the most energy efficient products on the market.

The way consumers access information has changed rapidly in recent years; this, in turn, has significantly influenced the purchase decision-making process. Information published online makes it possible and easy for consumers to directly search and compare products; superseding traditional in-store sales advice to some extent.

This initiative reacts to mainstream trends for smartphone use as well as for adoption social media like Facebook or Twitter and provides the roll out of an “Efficiency adviser” smartphone app (available from late autumn 2013). The guidance app will be easy to use and accessed through mobile devices as smartphones and tablets for product identification and in-store advice, covering the most relevant consumer decision-making criteria, namely: cost, product quality and energy efficiency. Smartphone optimized consumer web portals will be used to raise awareness of the benefits of energy efficient and sustainable products and social media channels will encourage users to share the information with friends and family.

This project will specifically target the online ‘early adopters’ and ‘early majority’ (also called internet natives) but will also serve the more than 70% of European households that are connected to the Internet aiming at energy aware purchase decisions and effective change of user behaviour regarding every day energy use.

Starting point

Household electricity consumption

The electrical energy consumption in the domestic sector in EU countries has risen significantly for more than two decades (e.g. in Austria increase by 30 % within 1990 and 2006, since then almost stagnating [1], for EU 27 the overall situation is quite similar with an increase by 35 % within 1990 and 2006 and a reduction by 1.5% onwards from 2006 to 2011 [2]). First of all raised saturation levels for appliances in households as well as demographic trends were effective as main influencing factors for the growth in consumption. An enormous energy efficiency increase plays a crucial role in many scenarios in the context of energy politics to exploit all potentials for energy savings and to maintain a significant reduction of electricity consumption in the household sector.

Spontaneous purchase decisions and lack of sufficient guidance in shops

In the vast majority of purchase decisions, "energy efficiency" is not usually a key deciding factor. Purchase decisions are sometimes made spontaneously (this applies especially for cases where a certain – individually different – price limit is not exceeded).[3], [4]

Only a very limited share of people are willing to or capable of investing a significant time for gathering information and comparison of different products prior to the purchase decision. More likely people will search for the cheapest price of a certain product, possibly preselected in a more or less arbitrary manner. A decent share of consumers only relies on advertisement information and marketing oriented messages beside the price tag to select appliances.

Advice in shop is a crucial element in guiding consumers, but unfortunately quite too often sales personnel is not sufficiently trained or willing to explain the benefits of higher efficient (and sometimes more expensive) products. As a consequence the situation where thorough guidance of customers in shops takes place is definitely not common, as this service most likely, but still limited will be offered in specialist shops. The benefits of more efficient products in terms of lower running costs and possibly higher product quality will be overlooked or underestimated. As a consequence customers would purchase appliances with rather poor efficiency even if they were willing to choose high efficient products.

Major retail chains in the sector "electric and electronic products" are apparently understaffed; hence customers have to rely on information printed on product packages or on labels only. The situation in terms of appropriate customer information is even worse in the case of mixed food/non-food markets selling appliances as part of their assortments.

Especially young customers expect to find information concerning product purchase online or even by mobile access to the Internet. Classic means of information, like printed articles, flyers, etc. are getting less relevant. This obvious trend is actually hitting the overall mainstream thus forcing market players to establish and promote appropriate information services online.

The long tail of disadvantageous (purchase) decisions

Appliances partly have long product lives – up to and beyond 10 years, depending on the product category. Inefficient products will cause high accumulated running costs.

The revised EU efficiency label improves the market transparency in terms of energy efficiency again; but will challenge the consumers' understanding of labelling classes and their interpretation regarding the product's life cycle costs.

Consumers' perceptions of labels and efficiency classes

Learning from previous experience gained from the Eurotopten-Network, people will need some time to actually learn how to consider the information displayed on the label. As classes of the European Energy efficiency label have not been readjusted, thus new products will likely populate classes from A upwards, many consumer will expect no real improvement by choosing classes beyond A (being for very long time the best class available)[5]. For example only a very few consumers will expect a 40 % energy saving, choosing an A+++ fridge instead of an A+ (actually now representing the minimum efficiency standard stipulated by Regulation 643/2009). The revised labelling scheme for directional and non-directional lamps valid by September 2013 will again challenge customers to really understand differences in running costs and efficiency. The relatively newly introduced label for TVs covers an important section in consumer electronics segment, but will have to be moved to the customers' focus.

Green commercial messages vs. factual label data

In the light of this, there is significant need for complementary measures targeting the choice. Considering the huge diversity of (non standardized) product declarations and labels introduced by manufacturers on the market, uncertainty on different levels will challenge consumers making an informed decision.

It is very obvious that consumers risk confusion between official labelling schemes and multiple green commercial messages. Quite understandably consumers do not want to focus on efficiency only but would consider quality related aspects as well. Merging the levels quality, efficiency and price in an easy accessible service, especially on the point of sale, even independent from sales personnel, will be seen as significant advantage and added value from the customers' view. Concluding from the aspects mentioned above developing and disseminating an easily accessible information service on EU level - meeting crucial requirements as high quality, neutrality, timeliness, will be obligatory to significantly increase the share of sustainable and energy efficient products.

Purchase of efficient products AND efficient use – need for day to day behaviour change

Aiming at effective energy savings, the purchase of efficient products is an important precondition. However the efficient use of appliances in day to day life is important either. People e.g. need to understand how to enable power management features, to be aware that eco programmes will take more time and thus save energy according to Sinner's circle (as a composition of the factors temperature, chemistry, time, mechanics) opposite to express programs, most likely consuming more energy but finishing sooner, and so on. To exploit the full potential of energy savings efforts have to be made to effectively change energy use behaviour as well. This support of course has to be helpful, relevant, low-threshold and easy to use, to be appreciated and accepted by consumers. Thus ideally guidance regarding selecting efficient products will be accompanied by specific advice for energy- and cost efficient routine use.

Social media and the role of smartphone use

Internet User in Europe

Access to Internet media is a standard for most of European households, actually independent from social stratum, purchase power and age. For the region directly covered by the partners in the consortium almost 175 Million adults (older than 14 years) are using the Internet, these are already two thirds in average of the overall population.

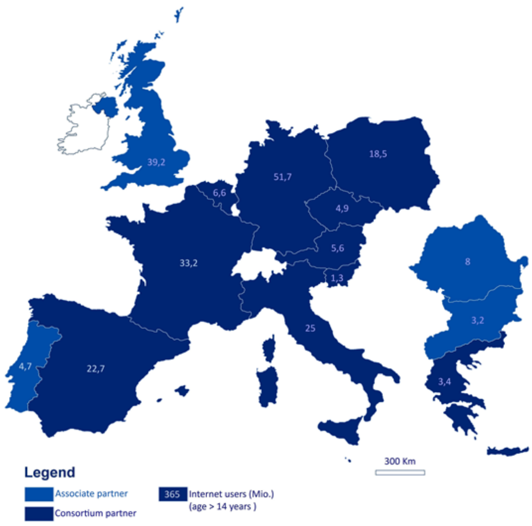

Figure 1: Coverage of "Efficiency 2.1" (Source: Austrian Energy Agency, 2013)

Table: Internet Use in Europe 2011 / Markets directly covered by initiative "Efficiency 2.1": (Source: GfK Online Monitor, GfK Austria, January 2012)

	Internet users (age > 14 years) [Mio]	Internet users (age > 14 years) [%]
Austria	5,6	79
Germany	51,7	73
Czech Republic	4,9	57
Italy	25,0	50
Spain	22,7	57
Poland	18,5	61
Slovenia	1,3	79
Greece	3,4	49
Belgium	6,6	78
France	33,2	60
Total	**172,9**	**Avg. 64,3**

Social media reach

Amongst many social media, Facebook is the most widely used one. The EU average monthly penetration of the Internet user population amounts to 63.6 % (data for 2011). Despite the fact that Facebook has been available for years, trends still indicate increases in use, for example, in Germany Facebook accounts grew by 43 % from March 2011 to March 2012. [6]

Smartphone penetration in target region and trend

Smart phones are already widely used in Europe. Within one year the share of smartphones compared to total mobile phone users grew from 31 % to 44 % (Dec. 2010 – Dec 2011). In December 2012 all European countries crossed the 50% mark for smartphone penetration. The highest adoption of smartphones is documented for Spain with 66%, followed by UK with 64 %, while the EU average lies at a level of 57%. Even 75 % of phones were smartphones acquired in December 2012. [7]

Quite interesting and being an important factor for success regarding the "Efficiency 2.1" strategy the smartphone use is not limited to a certain age range. However the age segment "25 – 34 years" is insignificantly dominating (averages for Germany, Italy, France, Spain and UK).

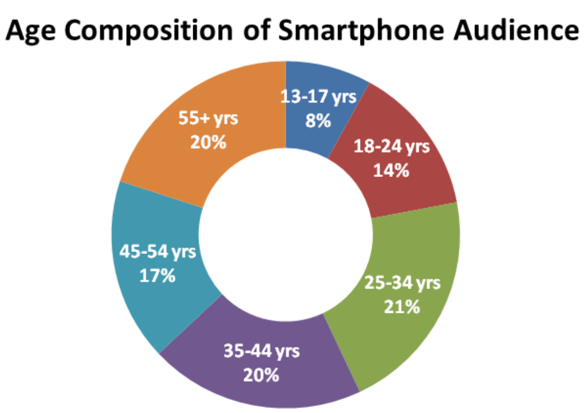

Figure 2: Age Composition of Smartphone Audience

(Source: Comscore, Europe Digital Future in Focus 2013, March 2013)

Smart phone use related to purchasing products

Until now there is limited evidence-based data on the interaction of smartphone usage/penetration and mobile consumer behaviour. But in "Our Mobile Planet: Austria, Understanding the Mobile Consumer" (May 2012) Google points out, that 67% of smartphone users do not leave home without their device, 98% use smartphones at home and 71% while being in a store.

The same study (which is also available for US, Denmark and Ireland with more or less similar results) highlights that smartphone users seek information concerning daily life on a regular basis: 58% of smartphone users search for product info, followed by items "Restaurants, Pubs" and "Travel".

Again the outcomes of this user survey prove that smartphones are primary shopping companions for a significant share of users: 20 % agree to the statement "I intentionally have my smart phone with me to compare prices and inform myself about products. Even 16 % commit to the statement "I have changed my mind about purchasing a product or service in store as a result of information I gathered using my smartphone."

The Initiative "Efficiency_2.1"

In designing the initiative "Efficiency 2.1" (funded by the Programme Intelligent Energy Europe) the following important aspects have been kept in mind, summing up framework conditions discussed above:

- The share of adults who are using the internet is considerably high: in average two thirds, in some EU countries almost 80 %.
- Social media (Facebook, Twitter, etc.) have been attractive for a huge share of internet users; the number of accounts is still increasing.
- Smartphone penetration is growing rapidly, showing an increase of 40% within one year. Especially the age segment 25 – 34 years represents the biggest share. Smartphone apps and their regular use represent the day to day standard.
- Online information sources linked to product data and sources of supply like price comparison portals are extremely popular. Moreover, smart phone apps being designed for accessing detailed product data are in demand. This e.g. is proven by the download statistics for the comprehensive shopping app Barcoo, which has been installed more than 2.5 million times in Germany.
- Nevertheless the above mentioned online channels and services are seldom linked to energy efficiency or aspects of consumer behaviour change.

Assuming that the daily time for using communication and information media (for private purpose) is limited to some extent, it seems to be obligatory to focus information and promotion regarding purchase and use of sustainable and efficient products to the channels with priority right from now. Otherwise, there is a risk that awareness and information regarding efficiency could lose ground again.

Thus the main objective of this project is to support consumers in their purchase decisions by providing up-to-date information about the most energy efficient products on the market by using this new means of information. This will be done through the development of an "Efficiency Adviser" smartphone app that is easy to use and access through mobile devices as smartphones and tablets. Smartphone optimized consumer web portals (including Euro-topten sites) will be used to raise awareness of the benefits of energy efficient and sustainable products and social media channels (e.g. Twitter and Facebook) will encourage users to share the information with friends and family.

Consequently the main project objectives of “Efficiency 2.1” are

- Drive demand for higher efficient and sustainable products and solutions, by providing user-friendly mobile accessible information that will help and encourage consumers to choose these products.
- Fill the current gap in the retail sector by providing up-to-date advice about energy efficient and sustainable purchase and use of products directly at the point of sale.
- Support awareness of especially younger consumers for energy efficient purchase and use of products and enhancing energy aware and ecological sound behaviour in everyday life.
- Support the effective implementation of labelling regulations for white goods, (replacing the existing well-known efficiency label), TV sets and domestic lighting as well as established product declaration schemes for office equipment by implementing information measures, which help over viewing the overwhelming number of multiple green commercial messages.

The following major outputs lay the basis for striving the goals described above

- An “Efficiency adviser” smartphone app will be rolled out for product identification and in-store advice, covering the most relevant consumer decision-making criteria, namely: cost, product quality (if data from third party sources are available) and energy efficiency.
- web portals and social media channels (Twitter, Facebook) will be established dedicated to sustainable and energy efficient products and their energy- and eco-conscious use, benefitting from synergies with existing initiatives and programmes (e.g. top lists, independent product testing sites, labelling programmes, etc.).
- A broad involvement of stakeholders and experts is maintained, keeping experts informed through an news feed (Twitter) fed into an EU-level platform, serving as hub for all activities at a national level.

Consequently, it seems quite clear that the initiative “Efficiency 2.1” can effectively support closing the common gap in very popular online information sources regarding easy to use guidance for efficient purchase and use by establishing a high quality, neutral, up to date and EU wide aligned information service. Concluding from the observation mentioned above the EU initiative “Efficiency_2.1” preliminary insights the app “Efficiency Advisor” can effectively impact the day to day live user behavior of the addressed target group concerning consumption and energy usage on two levels – as source of inspiration and incentive in the “day to day” mode as well as backing guidance in the selection and purchase of devices in shops.

Basic concept for EU-wide app “Efficiency Advisor”

Generally the smartphone app “Efficiency Adviser” will guide consumers on two different levels:

- Shopping mode: assisting the selection of energy efficient and sustainable products on the point of sale
- Day to day mode: supporting consumers in leading an energy efficient and eco conscious lifestyle aiming at a stimulation of behavioural changes.

In the following both service levels are briefly described. The actual implementation of the app, available in autumn 2013, will be based on design process, including thorough evaluation of user needs and expectation as well as usability testing.

Shopping mode:

- App offers support for selecting products in a certain product category, based on user input (relevant product category plus size of household for cold appliances, view distance for TV) including relevant information regarding features (interfaces, protocols, low power modes)

- Show data for best performing products in given category (TV 42/48 Inch screen size, On mode XX / YY Watt) providing an added value for comparison of different products
- Provide a list of up to date actual available best performing products (topten product lists)
- Based on the database entry the app delivers an info regarding product test from independent testing institutes showing test result and providing link to test report (with costs if applicable)
- The app offers a simple cost calculator for comparing different products (two TVs, A resp. B class) evaluating total costs (purchase price and running costs for project lifetime) to assist eco-conscious purchase decisions (based on default settings).
- Show user generated content to related product features, (only if defined quality criteria are met)

Day to day mode:

- App presents key word filtered (filter on hashtags, e.g. "#LED") content from social media channels provided by partner portals.
- The App offers a direct communication channel to social media sites as well. The User is able to post messages to Facebook, Google+ and Twitter and is able to upload pictures to the social media sites.
- App shows energy advise at least once per week ("tip of the day", "did you know?")
- In the case of co-branded version: App delivers appropriate topic oriented content from cooperating key market actor

Especially implementing the feature "Continuous news feed / social media link" will be essential as it makes sure that smartphone users are encouraged to actually download and use this app as it has the capability of delivering a daily basis service and helps keeping in mind, that the app is installed once a product will be purchased. Consequently this specific feature has to be highlighted in promotional tasks. Thinking of a smartphone app without this feature customers could be reluctant regarding the installation as then they expect a rather seldom everyday use.

Figure 3: dummy front end of smartphone application "Efficiency Adviser"

Relation to Euro-topten-Network and other related initiatives

It's worthwhile to emphasize that the initiative "Efficiency 2.1" considers two crucial aspects concerning scope and objective:

First it's not intended establishing a new brand, which would have to be communicated to consumers. However the project will focus on coupling and connecting to existing successful and already known initiatives at the national level, hence enhancing the service for consumers.

Second "Efficiency 2.1" will complement existing activities and avoiding duplication: The logic of this activity is consciously designed to preclude any duplication with existing activities. Instead, it will appear joined up from the consumers' perspective by transferring relevant information to attractive, up-to-date channels (via social media and accessible at the point of sale.) The project will make use of, and further promote, the outputs and synergies provided by the Euro-Topten-Max and other relevant IEE projects.

Especially this initiative is implemented as a complementary service to the Eurotopten-Network. Euro-topten is a consumer-oriented online search tool, which presents the best appliances in various categories of products. The key criteria are energy efficiency, impact on the environment, health and quality. Topten was launched in 2000 in Switzerland. Since then, sixteen other national Topten sites have been established, thanks to the European IEE-projects Euro-Topten, Euro-Topten Plus and today Euro-Topten Max (Intelligent Energy Europe). Each Topten website provides a selection of best appliances from the energy point of view. Topten information targets consumers (pictures, functions, price, no complex calculation, for products available locally in their country) and large buyers. Topten is rigorous and transparent, independent from producers and commercial distributors. Topten relies on neutral tests and analysis of independent institutions, labels and on standardized declarations of manufacturers (e.g. EU-directives for household appliances). www.topten.eu serves as a portal to reach all sites of participating countries. Beyond that "Efficiency 2.1" will collaborate with other EU projects and initiatives like Coolproducts, PremiumLight, Marketwatch, etc.

Role of key actors and co-operation partners

An intense cooperation with key actors is indeed a core activity within this initiative aiming at significant increase in promotion coverage and lay the groundwork for a permanent maintenance of the provided services – various smart phone app versions and social media channels – even beyond the project lifetime.

Beyond the roll out of an independent smartphone app "Energy Adviser" the consortium further aims at implementing co-branded apps jointly with key market actors as well as incorporating core functionalities in already well-established apps. This activity will ensure gaining the widest possible outreach of this point-of-sale (POS) customer service. Several stakeholders have already expressed their interest for cooperation (energy utilities, price comparison platform, online advertisement portal, app provider, etc.)

For many market players (e.g. energy utilities, NGOs, etc.) it potentially will be a very appealing situation to use a semi-final smartphone app (white label version) and promote this service as their own product (ensuring that the IEE funding background will remain visible for users). Beyond the approach to establish and disseminate a pure IEE branded app the partners will aim at involving key players committing to use and widely promote this app in their branded version too. This will also lay the essential groundwork for the service provided beyond the project's time horizon.

Outlook

After the project start in April 2013 the preparation and design process as well the implementation of all social media channels will be finalized by summer. The smart phone app "Efficiency Advisor" as jointly developed service will be available by autumn. In September all results from the evaluation of user needs and experience gained from European wide usability testing will be presented to professional audience.

Co-funded by the Intelligent Energy Europe
Programme of the European Union

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What is the price of energy efficiency or which appliance efficiency class is the most suitable?

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Abstract

Electricity used for household appliances can represent an important part of the overall building energy balance and operational costs. Increasing electricity prices force our purchasing decisions to be more elaborated, and energy efficiency is their vital element. An important question is: can an average consumer get a comprehensive impression about long-term effects of the purchase based on data currently available at the point of sale?

An indicator showing average annual operational costs for a particular appliance can be a helpful tool, helping consumers to make reasonable decisions for the long-term framework. This type of information also fosters transition in consumer behaviour from the lowest cost orientation to economically most viable option, thus providing firm reasoning for green decisions in private and public procurement. It can also help in transforming the market towards a consumer-friendlier one. In this context Slovenia is taking part in two Intelligent Energy Europe projects entitled Yearly Appliance Energy Cost Indication (YAECI), and (green procurement-oriented) BuySmart+.

The relevance of elaborating energy cost indicators for the Slovenian appliances' market is underlined in the paper, the market itself is analysed and typical energy use data are presented. Aspects of energy cost indication are shown, among other the retailer point of view and reasons for cooperation (e.g. upgraded service for customers, market competition, improved company profile), and the consumer point of view received as feedback to two polls conducted by ZRMK (e.g. energy costs indication at point of sale, eventual influence upon change in purchasing practice and decisions).

1. Slovenian market of household appliances – past and current situation

Slovenian market of household appliances is well developed with regard to both variety of brands and models available as well as their technical and environmental quality. Also, as all the major international manufacturers are present in Slovenian shops it can be said that during the last two decades the situation has evolved to a level quite similar to other EU countries.

Households are a significant consumer of electricity, where the appliances play a very important role. Official statistical data for Slovenia [1] show that until the year 2007 electricity consumption was increasing fast. The global crisis hitting also many segments of Slovenian economy discontinued this trend. However, the household sector has some particular characteristics. In 2010 the share of electricity consumed in the household sector was 27%, nominally being the largest since 1991 and exceeding the figures from 2000 by almost one quarter.

This situation can be viewed at from different angles. On one hand it is related to the rising number of apartments, which brings along a higher number of household appliances. For example, comparison of inventories from 1991 and 2002 shows an increase in the number of apartments by almost 95000. The national statistics quotes that around 92% of residential buildings or apartments are owned privately. On the other hand, the number of building permits issued has been decreasing since 2007; in 2010 14.6% less permits than in 2009 were issued, and in 2011 6.8% less than in 2010. This means fewer purchased appliances for new apartments, with the sales reflecting a shift towards a larger share of appliances bought to replace old ones.

It can be reasoned that not only a higher number of appliances, but also their more frequent and intensified use related to changed living habits and patterns contribute to higher electricity consumption, although contemporary products have a significantly improved energy efficiency. According to estimations on an average around 1000 large household appliances are being sold annually in Slovenia [2], which has a population of slightly over 2 million.

The latest Energy Efficiency Status Report by JRC [3] states that final residential electricity consumption accounted for 29.71% of total final electricity consumption in the year 2010. Compared to this figure the final electricity consumption in the Slovenian residential sector is slightly below the EU-27 average.

It is interesting to observe the shares of some of the more significant appliances in the annual electricity consumption as included in the report. If we focus on the ones with a nearly 100% market saturation in Slovenia, namely refrigerators (usually as a refrigerator-freezer combination) and washing machines, we see that they fall into the "cold appliances" category with a 14,5% share, and "washing and drying" category with a 7,2% share on the EU-27 level, as illustrated in the figure below.

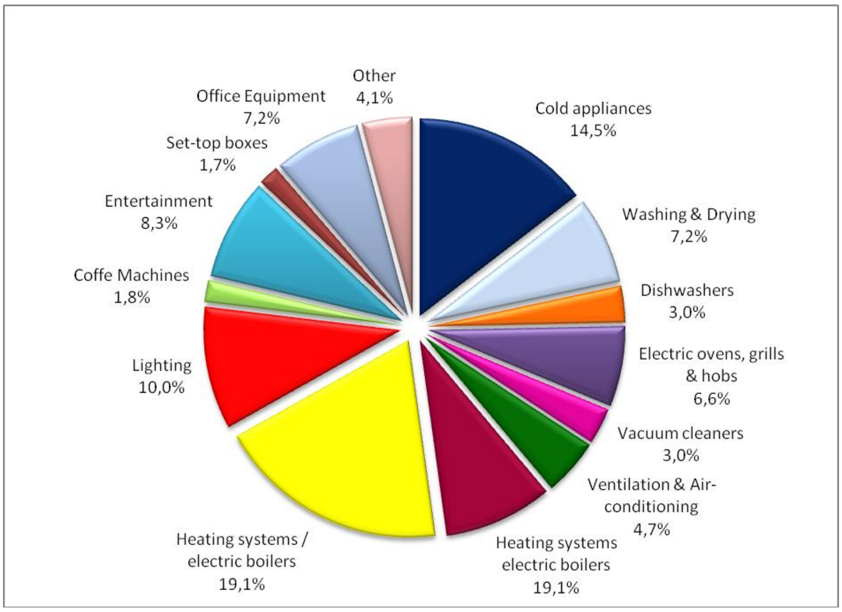

Figure 1: Residential electricity consumption breakdown in the EU-27; status 2009. (Source: [3])

The report brings an important conclusion, which confirms the above discussion about the situation in Slovenia; quote: "Residential electricity consumption is still rising. Although many appliances are becoming more efficient, the number of appliances is rising, appliances are used more often and for longer periods of time, and many appliances have more functions or special features that require more energy. The general trend in the residential sector is therefore an increase in electricity consumption."

In the Slovenian non-residential sector trends related to appliances are similar, although not that dynamic. Since 2012 the public sector has to comply with specific rules for green public procurement, which will be presented in more detail below.

The most recent (2013) Energy Efficiency Watch report for Slovenia [4] states that the policy package for appliances is to a large extent based on the implementation of the EU Directives on ecodesign and energy labelling. Currently there are no public subsidies available for purchase of energy efficient household appliances, but some commercial banks offer favourable loans with lower interest rate for such purpose.

2. Energy efficient appliances in the Slovenian strategic framework

National short- and mid-term energy and environmental strategies and goals in Slovenia are in line with the EU framework and related targets, for instance with the Directive on Energy Efficiency 2012/27/EU requesting purchase of products, services and buildings with high energy efficiency performance. For the appliances' sector labelling of products and gradual phasing out of inefficient models represent the starting point for improvements and progress. The public sector is supposed to play the leading role and represent a good example to the private one, based also on the requirements of the Decree on Green Public Procurement.

2.1 Decree on Green Public Procurement

Green (public) procurement has been identified as one of the crucial elements of national strategies oriented towards sustainable growth, low-carbon society and nearly zero energy buildings. Slovenian authorities have in the recent past taken more concrete steps for improvement of the usual procurement practice using solely the lowest price as a predominant selection criterion. In the year 2007 the lowest price as the only selection criterion was used in 79,81% of all procurement cases by value, and in 73,48% of all procurement cases by number. The national Action Plan on GPP 2009-2012, AP GPP [5], set targets in accordance with the EU ones, and it was followed by development of a specific decree bringing forward requirements and selection criteria for 11 product groups. The Decree on Green Public Procurement [6] prepared on the basis of AP GPP strategy has been in use since March 2012. It is a mandatory operational document and has the status of a regulation.

The decree sets basic (core) environmental requirements, which are the mandatory level, and additional environmental requirements in the primary sense of recommendations. Procurement bodies have of course a free choice of shaping further, more rigorous requirements. One of the product groups where consideration of these legal obligations is mandatory comprises refrigerators, freezers, combined refrigerators and freezers, washing machines, dishwashers, and air conditioners.

The technical specifications and selection criteria for the above mentioned appliance types all follow the same principle of using the energy label as the starting point. Technical specifications used as minimum requirements are: class A+ or higher for refrigerators, freezers, combined refrigerators and freezers, washing machines, and dishwashers, and class A or higher for air conditioners. Selection criteria are based on the bonus points principle, i.e. the offer is given additional points for A++ and A+ class (or higher) appliances, respectively. The procurer shall define the method for bonus calculation and the share of these criteria in the overall set. There are additional bonus points possibilities included in the decree regarding the selection criteria: class A or higher for the wringing cycle (washing machines), and class A or higher for the drying cycle (dishwashers).

The ZRMK institute representatives cooperated in the work of a special expert group appointed by the Government, with a task of preparing draft structure of the decree and its product appendices, and of defining the core and additional criteria and technical specifications. Here our experience from the Intelligent Energy Europe project Buy Smart+ (and its predecessors Buy Smart and GreenLabelsPurchase) proved to be very useful [7]. The project addresses both private companies and public authorities, and offers free consultation, guidelines and procurement tools, information about procurement directives and labels, good practice database and other materials of interest. The product groups considered are building components, green electricity, lighting, office equipment and vehicles, and also household appliances.

The decree will certainly go through changes and be upgraded in the future, especially concerning the product groups where technological development is fast or where the labelling scheme undergoes amendments. The national GPP legislation directly relates also to some other fields, one of the more important being EPBD-based regulation on energy efficiency of buildings. At first sight maybe not very obvious, but potentially important can be the range and type of input data for future building energy performance calculation method. Namely, a very important topic which all Member States need to deal with already at this moment is the national definition of a “nearly Zero Energy Building” (nZEB). To formulate the most appropriate nZEB criteria several questions need to be answered, one of them touching also the appliances’ sector: where will the system border be set and how detailed will the “energy” definition be, i.e. will the appliances be included in it. If yes, then the demand for most efficient products will grow faster, fostering also the development and manufacturing of new advanced products, and provision of additional information. Not only that, as the nZEB level will be mandatory for new public buildings already from 2018 on, the green public procurement criteria could need to be amended also considering this aspects. From this brief overview of a particular Slovenian regulatory segment it can be seen that many topics are interlinked and that in the future an instrument such as the YAECI indicator can play a noticeable direct or indirect role beyond the current one.

3. Energy efficiency versus investment and operational costs of appliances

Electricity used for various domestic appliances as reflected on monthly bills for operational costs can represent an important part of the overall building energy balance. The more efficient a building is the larger is the relative share of electricity consumption in the delivered energy score. It is somehow understandable that a highly energy efficient building is equipped with highly efficient products. But, as a consequence of increasing living costs related to electricity prices the purchasing decisions need to be more elaborated, and energy efficiency is becoming a logical yet sometimes not clear enough criterion. A very important question is: can an average consumer, be it private or public, get a comprehensive impression about long-term effects of the purchase based on data currently available at the point of sale?

For the appliances the same basic principle is to be followed as for the building energy efficiency itself. An analysis of long-term effects of individual choices and their impact on the overall performance is needed to gain the most profit out of the investment. At the same time another important fact has to be taken into account: electricity consumption and related operational costs depend also upon user behaviour, and patterns, frequency and duration of use.

It is fair to assume that data about average annual operational costs calculated according to a uniform method for a particular appliance can be one of the most helpful tools for the consumers, helping them to make reasonable decisions and bringing forward long-term advantages of buying a maybe somewhat more expensive yet much more efficient appliance in terms of energy use. This type of information also fosters transition in consumer behaviour from the lowest cost orientation to economically most viable option, and thus provides firm and clear reasoning for green procurement decision-making process in private as well in the public sector. Such an instrument can gradually bring further improvements and help in transforming the market towards a greener and consumer-friendlier one.

3.1 Indicator of operational costs as additional consumer information

Experienced partners from 11 European countries, including Slovenia with the ZRMK institute, have formed a consortium under coordination of the NL Agency and started developing a voluntary indicator as described above [8]. The project (Yearly Appliance Energy Costs Indication; YAECI) has been supported by the Intelligent Energy Europe programme. It is based on a successful Dutch practice EnergieWeter. The main objective of the project is to provide customers with information at the point of sale on the yearly energy cost of products with an energy label, in order to stimulate the uptake of affordable efficient products.

As discussed above, the EU energy label currently provides the consumer with information on the energy efficiency (energy class), energy consumption and several other energy-related aspects. However, it lacks the information about an aspect that many consumers find very important, i.e. the product´s (yearly) running costs. The calculation of costs follows a common method based on data from the energy label and average national electricity and water prices. For products with the old energy label the method has been modified to allow for comparison with the new labelling.

There are at least two major yet slightly different aspects of presenting these data at the point of sale (shop, catalogue, Internet). Firstly, consumers are able to better comprehend the difference between more and less efficient products when it is illustrated by lower operational costs for the first group. In this way the usually higher price of a more efficient product seizes to be perceived as a disadvantage frequently posing as an obstacle for a purchasing decision in favour of such items. Secondly, there may be cases when some product would for one reason or another be only seldom used, i.e. with much lower frequency than in a “standard” pattern of use. In such a situation the cost indicator would show that purchasing a more expensive and more energy efficient appliance would not bring long-term advantages as the operational costs’ savings would not cover the price difference. This can be done in a simple way by checking the ratio between price difference and annual energy costs difference.

An example: a customer compares a highly energy efficient but more expensive (price: 400 EUR) appliance with a less efficient but cheaper (price: 350 EUR) one. Let us say that with “average (standard, normal, ...) use” the energy costs are 30 EUR/a and 39 EUR/a, respectively. The price difference would be covered by a reduction of energy costs in ca. 5 years (50 EUR/9 EUR), so the purchase of a more efficient appliance seems completely rational and beneficial. However, in a case when the intended use is only occasional, for instance only one third of the “average” one, the energy costs would be only 10 EUR/a and 13 EUR/a, respectively. In this case the price difference would be covered by reduction of energy costs only in ca. 16 years (50 EUR/3 EUR), which may even be past the technical lifetime of a particular appliance.

Of course, points of sale will be equipped with simple but clear information for customers about the considered average use patterns of appliances fitted with indicators. These data and the calculation methodology behind the YAECI indicator are for each appliance type presented in detail in a report publicly available at the YAECI website (http://www.appliance-energy-costs.eu/eu/library/library).

It may be argued that the second case does not represent green purchasing decisions, but only if we look at the subject in a very narrow way, not taking into account the principle of searching for an economically most viable offer and the fact that lower usage rate also means lower electricity consumption and related lower negative environmental effects.

Although the visual appearance of the indicator has not been defined within the YAECI consortium to allow for customisation for different use options such as on a price tag, as an individual label and similar, in Slovenia the decision has been made to prepare a unified design. This initiative came in fact from the side of the largest retailers, pointing out that such an instrument needs own graphical identity so that the buyers will recognize it and accept it more quickly. Therefore the indicator carries the project logo and the text “Yearly energy costs” followed by the value expressed in EUR as illustrated in the figure below.

Figure 2: An example of the YAECI indicator for the Slovenian market. (Source: ZRMK)

4. Selected statistical data for Slovenia

The Statistical Office of the Republic of Slovenia provides access to statistical data from various sources and about various categories on its web portal [9], also about electricity consumption in households including information about electrical appliances and the shares of labelled ones. If we take a look at washing machines, refrigerators (also combined with freezers) and dishwashers we can see that in the year 2010 there were about two thirds of these appliances equipped with an energy label: washing machines, 65,3%; refrigerators (+freezers), 64,7%; dishwashers, 72,2%. Having in mind that in Slovenia energy labelling started in practice about a decade ago we can estimate that over two thirds of the mentioned appliances in use in Slovenian households are not older than ten years. The above mentioned statistical source offers further interesting data, some of which are presented in the figures below.

There are no official cumulative statistical data available which would allow for an estimation of the share of household appliances in the electricity consumption in the non-residential sector. This sector is very specific and the figures can vary significantly, for example between schools and hospitals on one side and office buildings on the other side. However, in relative terms the status can be estimated as being similar to the residential sector: continuous uptake of more efficient appliances both as first buy and as a replacement of old ones, increasing number of appliances or at least of some of the types due to technological upgrade, intensified and more frequent use.

Municipalities in Slovenia have an obligation to prepare local energy concepts (LEC), where the baseline conditions are established and various technically and economically feasible strategies for improvement of energy efficiency on the local level are defined. Current practice touches the share of electricity consumption as discussed in this paper only seldom, but with respect to the strategies for sustainable growth this aspect will probably have to find its place in the LECs as well.

A clear picture of electricity consumption range evolving from different sources can be established during energy audits, which are being carried out for example in Slovenian hospitals, schools and kindergartens as a precondition to apply for state funds for improvement of energy efficiency. Here again not only an estimation of improvements in technical terms is important, but also from the financial aspects. An indicator of operational costs for large appliances can offer valuable help as an input to mid- and long term financial flow projections and planning of necessary budget.

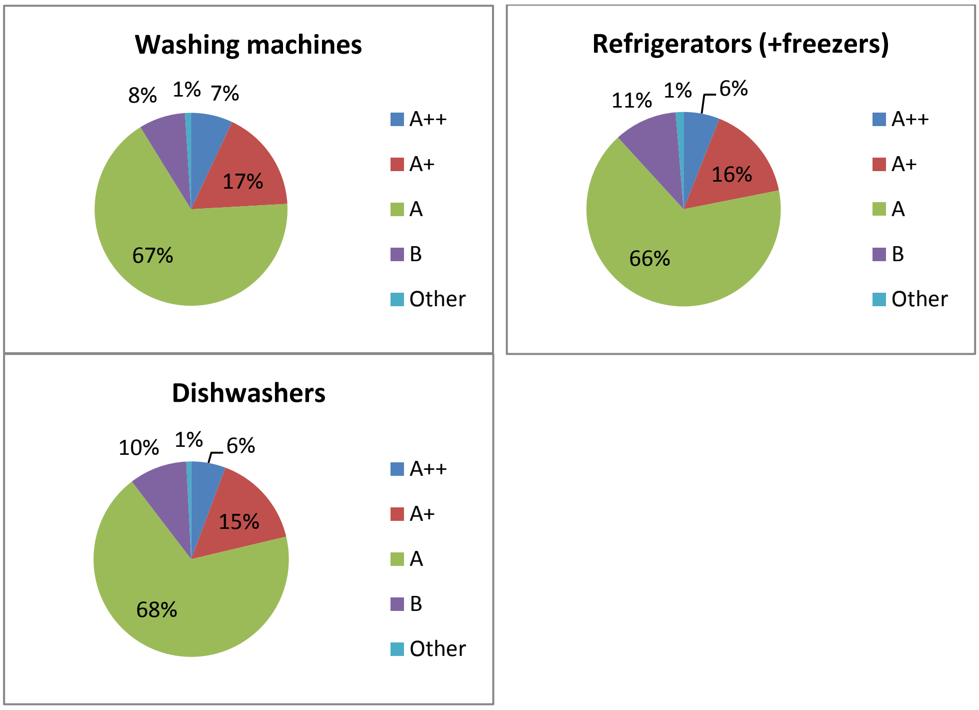

Figure 3: Energy label class shares, residential sector: washing machines, refrigerators (+freezers), dishwashers; status 2010. (Source: [9])

We can also observe (Fig. 4) that in the residential sector in the period between 2009 and 2011 the total electricity consumption for washing machines and refrigerators was slowly decreasing, which is probably due to uptake of more efficient products, not due to a reduced total number of these appliances. As opposed to this trend the consumption of dishwashers was slightly increasing, which can be related to a larger number of households, both old and new, equipped with this appliance.

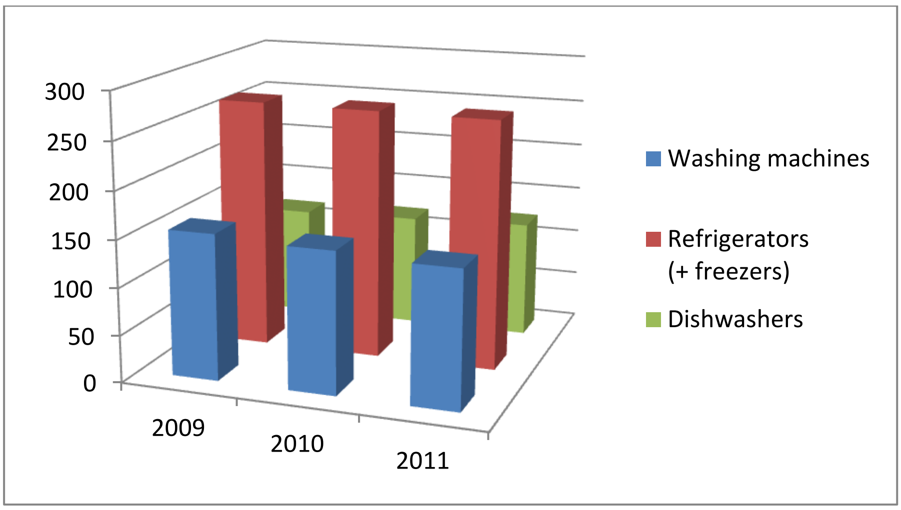

Figure 4: Annual electricity consumption for three selected products in GWh. (Source: [9])

5. Consumers’ and retailers’ point of view

Since the beginning of the IEE YAECI project in spring 2012 many promotional activities have been carried out in Slovenia by ZRMK, including presenting the indicator two times on the first programme of the national TV.

On the February 12, 2013 ZRMK presented YAECI project on the 1st programme of the Slovenian national TV in prime time just before the evening news. The additional information to consumers - appliances' operational costs was presented and explained at the interview. The second TV appearance was on March 5, 2013, when the Slovenian YAECI partner, ZRMK, went live into the national morning TV programme. The meaning and importance of energy labelling, and the idea of the yearly energy costs indicator for domestic appliances ware presented in the Merkur retailer trade centre in Ljubljana.

To obtain the consumers point of view about the energy labels, understanding of the appliances’ operational costs and about key aspects when purchasing a new appliance, two polls were conducted by ZRMK. The first one was distributed after the workshop about the energy efficiency of appliances at the DOM Fair, Ljubljana, from March 13 to 17, 2013. The second one was an electronic version sent randomly to different costumers who just recently made the purchase of an appliance or are planning to do so in the near future. Altogether 204 opinions were collected and are presented in the figures below.

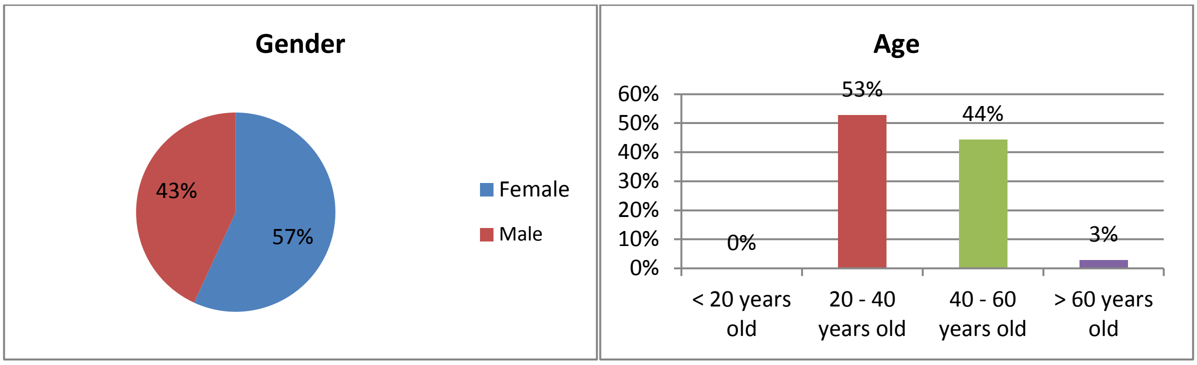

Figure 5: 114 female and 88 male persons mainly of the age from 20 to 60 years responded to the poll. (Source: ZRMK)

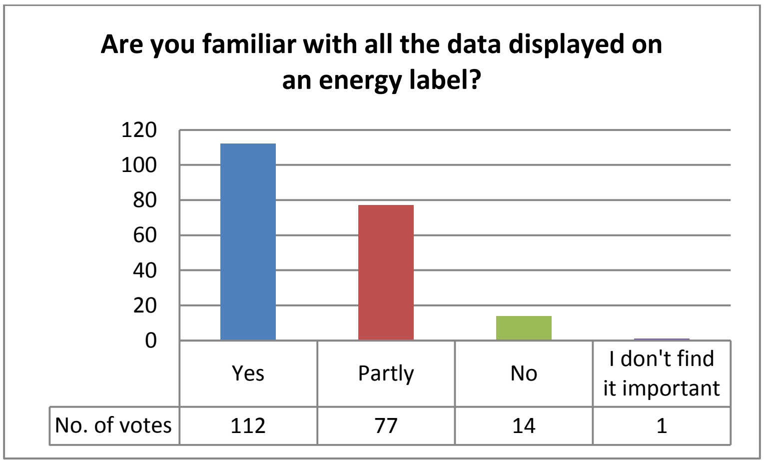

Figure 6: As seen from the chart the awareness about energy labels is quite high in Slovenia. (Source: ZRMK)

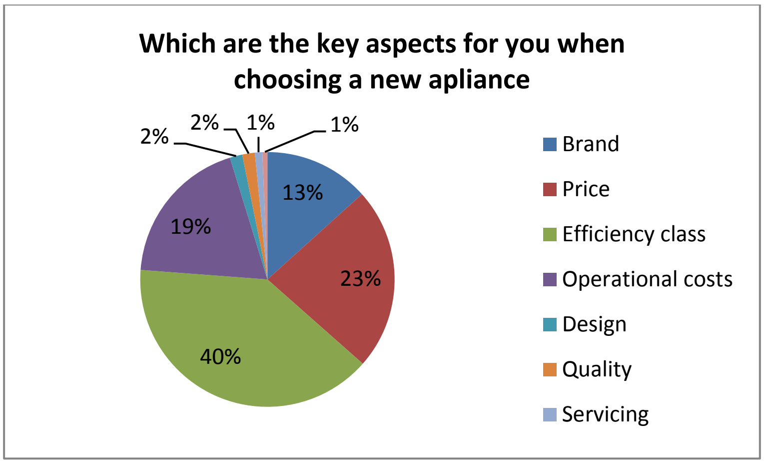

Figure 7: According to received answers the efficiency class followed by the price and operational costs are key elements when purchasing a new domestic appliance. (Source: ZRMK)

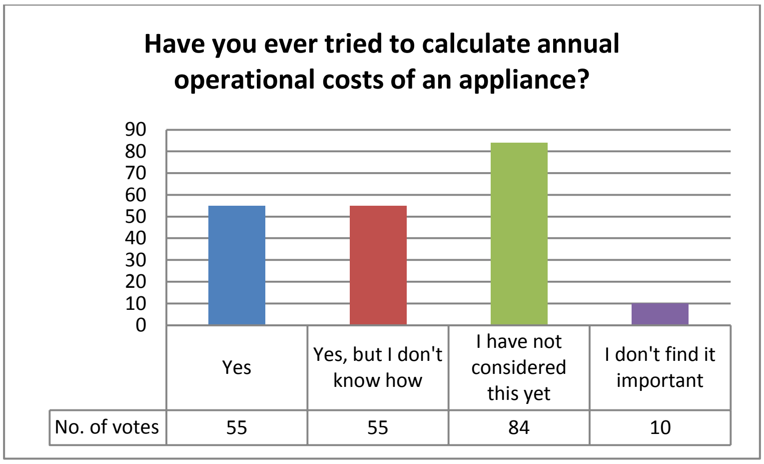

Figure 8: The calculation of annual operational cost of an appliance has proven to be a problem. The consumers are either not familiar with the calculation process or haven't considered it yet, basically for the reason of not knowing the methodology of calculation. (Source: ZRMK)

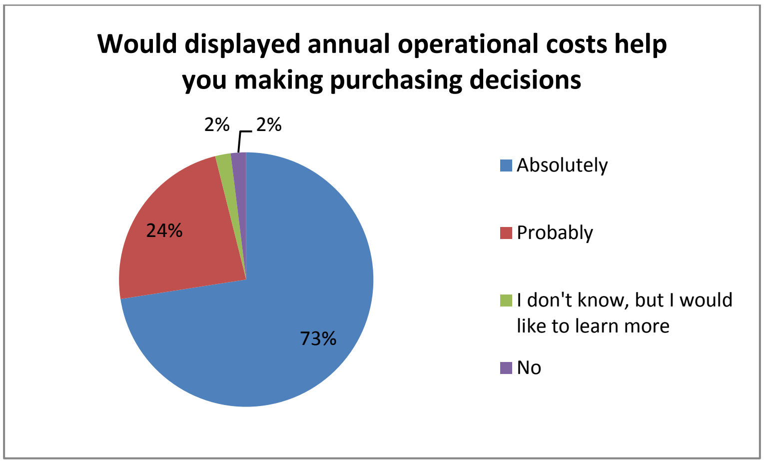

Figure 9: The final part of the poll shows that Slovenian consumers would highly appreciate additional information about the operational costs of an appliance. (Source: ZRMK)

The major Slovenian retailers contacted by ZRMK about YAECI so far underlined that one of the key elements of their approach to consumers is providing relevant and adequate information, be it in shops, catalogues or on their web pages. They confirmed great care of proper display of energy labels and showed interest in the cost indicator idea as an additional information for the buyers. The prevailing positive aspects seen from their side can be summarised as building up the company image of being environmentally aware and consumer friendly, keeping up with current EU and national standpoints, and using the indicator as a marketing tool to strengthen their position on the national market.

6. Conclusion

Electricity consumption and related costs used to be somehow in the shadow of consumption and costs for heating. With the rising thermal standard of buildings (new construction and renovation) and with increasing energy costs in general this segment is quickly gaining importance. Building owners and users are more attentive to the possibilities of reducing related operational costs. Household appliances can contribute a significant share to the overall expenditure of energy and financial resources.

Based on these facts it would be logical that the fundamental decision making process when purchasing a new appliance is similar to the one when selecting for example a new boiler: defining the actual need in technical terms, choosing an appropriately high level of energy efficiency, comparing prices, and estimating long-term effects and payback time. We are talking about green procurement here, irrespective of the fact that especially in the private sector many buyers don't actually think about such a definition, but do it in a self-evident way simply because they are looking for the most rational solutions according to their available budget.

As shown in the paper the general awareness about the energy label for domestic appliances is high, meaning that buyers know how to differentiate between more and less energy efficient products. Knowing how to use data from the label to calculate long-term costs related to operation of appliances is another question. According to our survey an indicator presenting these facts at the point of sale as developed within the IEE YAECI project will be warmly appreciated not only by buyers, but also by retailers. The advantages are obvious and manifold: additional information for the consumer, a transparent picture of the relation between product price and its operational costs, clearer advantages of selecting more efficient products and better basis for planning of future budget expenditure. These facts are important both for private and for public purchasers and contribute to meeting individual as well as local and national environmental targets combined with cost savings.

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Energy Profits with Controllable Electric Vehicle's Charger under Energy Box Decisions

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Acknowledgements

This work has been framed under the Energy for Sustainability Initiative of the University of Coimbra and partially supported by the Energy and Mobility for Sustainable Regions Project (CENTRO-07-0224-FEDER-002004) and by Fundação para a Ciência e a Tecnologia (FCT) under project grants MIT/SET/0018/2009, PTDC/EEA-EEL/121284/2010 and PEst-C/EEI/UI0308/2011.

ABSTRACT

Nowadays, there is a wide interest in the transformation of electric grids into smart grid, especially in the residential sector. This technology change provides the basis for a more efficient use of the electric power infrastructure at a global scale. Since electricity is an indispensable commodity for people, which has its own trade market, there is a growing need for technologies that make a sustainable, intelligent and optimized management of electricity. Thus, technologies have been presented based on demand-sensitive pricing strategies that already have proved to be effective for load profile changes such as the one mentioned in this paper, which is designated as Energy Box (EB). This is a benefic technology not only for the environment, but also for utilities and especially for the end users by referring to the domestic sector and their respective loads, emphasizing one “special” domestic load, which is the Electric Vehicle (EV).

Therefore, in this paper the EB technology, the demanding EV charger characteristics and the associated benefits regarding end users and utilities are examined. This paper also compares several case studies based on daily EV usage, electricity price evolution and EV batteries State-of-Charge. The presented results are based on ECE 15 standard driving cycle and different electricity tariffs, such as, single and two rate tariff, and dynamic tariff based on *OMIE* market prices which considers the access to networks tariffs for January 2013 in Portugal. For each case study, possible EB decisions concerning one random end user are presented and fully discussed. The battery life impact for the proposed application and the achieved monthly handling cost (€) are also approached.

Keywords: Electric Vehicles; Charger; Energy Profit; Vehicle to Grid; Energy Box.

INTRODUCTION

Currently the optimization of energetic resources usage, beholding the associated costs, is one of the most discussed hot topics, mainly when the crude oil and respective arising products are considered. The global aspects concerning the energy supply, leads to economic, ecologic and geopolitical issues, which are gaining today’s political and scientific attention. Contemporary society is increasingly dependent on energetic resources, with the fossil fuels being (e.g. coal, natural gas and crude oil) the most problematic, due to their limited existence and currently attained importance, which leads to their price instability. Only in Portugal during 2011 approximately 5.5 million tons just in fuels for the public transportation sector was expended [1].

The resulting emissions from thermoelectric plants and the massive utilization of internal combustion engine (ICE) vehicles, mainly in the transportation sector, substantially increase the global gas emissions. Carbon dioxide (CO_2) is probably the most famous greenhouse gas emitted to our atmosphere. During 2010 in Portugal, only from fossil sources approximately 53 thousand tons of this greenhouse gas was released [2]. ICE vehicles emissions are one of the major urban pollution sources, especially in medium and large cities, leading to public health issues, as air pollution contribute to mortality and morbidity [3]. Thus, it is easy to understand why pollution coefficients must be reduced in order to increase planet sustainability and life quality. The reduction of greenhouse gases emission could be achievable through losses reduction from generation, transmission, distribution and consumption of electrical power. This reduces the amount of produced energy needed, as well as the resulting pollution and greenhouse gas emissions, being achieved more efficient energy production systems. For this purpose, renewable resources and Electric Vehicles (EV) are considered good alternatives [4].

On the other hand, the smart grid applicability in the residential sector provides technological basis for a more efficient use of the electric power infrastructure at a global scale. Since electricity is a good indispensable for people commodity, which has its own trade market, there is a growing need for technologies that make a sustainable, intelligent and optimized management of electricity. Thus, technologies have been presented based on demand-sensitive pricing strategies that have already proved to be effective in altering patterns of electricity usage as the one mentioned in this paper, which is designated as Energy Box (EB). In fact, demand-sensitive pricing of electricity is expected to become the standard pricing mechanism in smart grids, maintaining electric system security and reliability at least cost. This is a benefic technology not only for the environment, but also for utilities and especially for the end users by referring to the domestic sector and their respective loads, emphasizing one “special” domestic load, which is the EV. These end users benefits are assigned based on their willingness in the assistance to the utility in several energy exchange scenarios, as the ones described further in this paper. Recent concepts and developments in EV philosophy and technology not only point for the need for charging (Grid to Vehicle – G2V) but also on delivering storage energy back to the grid (Vehicle to Grid – V2G), providing economic benefits for EV owners (end users) and utilities, decreasing the environmental impact through electricity generation plants and pollution reduction. Accordingly to this, technologies like the EB when attached to EV bidirectional and power adaptive chargers, as mentioned in this paper, will allow exploiting all the capacity and benefits of EB technology. This is possible by managing the EVs energy as they represent important loads or supplies in the end user and utilities perspective [5] [6]. Therefore, in this paper the EB technology is examined, including the demanding EV charger characteristics, how both are related, and the end users and utilities associated benefits are also discussed. Facing the enormous challenge of energetic exchanges between the EV and the grid, this paper approaches the importance of energy management, while maintaining the end user satisfaction level. Maintain electrical energy quality service without neglecting the dynamic electricity price changes is also highlighted. This paper also compares several case studies based on daily EV usage, electricity price evolution and EV batteries State-of-Charge (SoC). The presented results are based on ECE 15 standard driving cycle and different electricity tariffs, such as, single and two rate tariff, and dynamic tariff based on *OMIE* market prices considering the access to networks tariffs for January 2013 in Portugal. For each case study, possible EB decisions concerning one random end user are presented and fully discussed, as well as battery life impact for the proposed application and the achieved monthly handling cost (€).

ENERGY BOX CONCEPT AND ELECTRIC VEHICLE INTERACTION

The EB is proposed as a 24/7 operating technology for home or small business electrical energy usage management, which could take new actions within small step times (e.g. minute). EB is designed to operate in a demand-sensitive real-time pricing environment, which is feasible through smart grids technology evolution (see Figure 1). Thus, under this purpose it is assumed that, every electrical device in a home or small business will be controllable from one EB [6] [7].

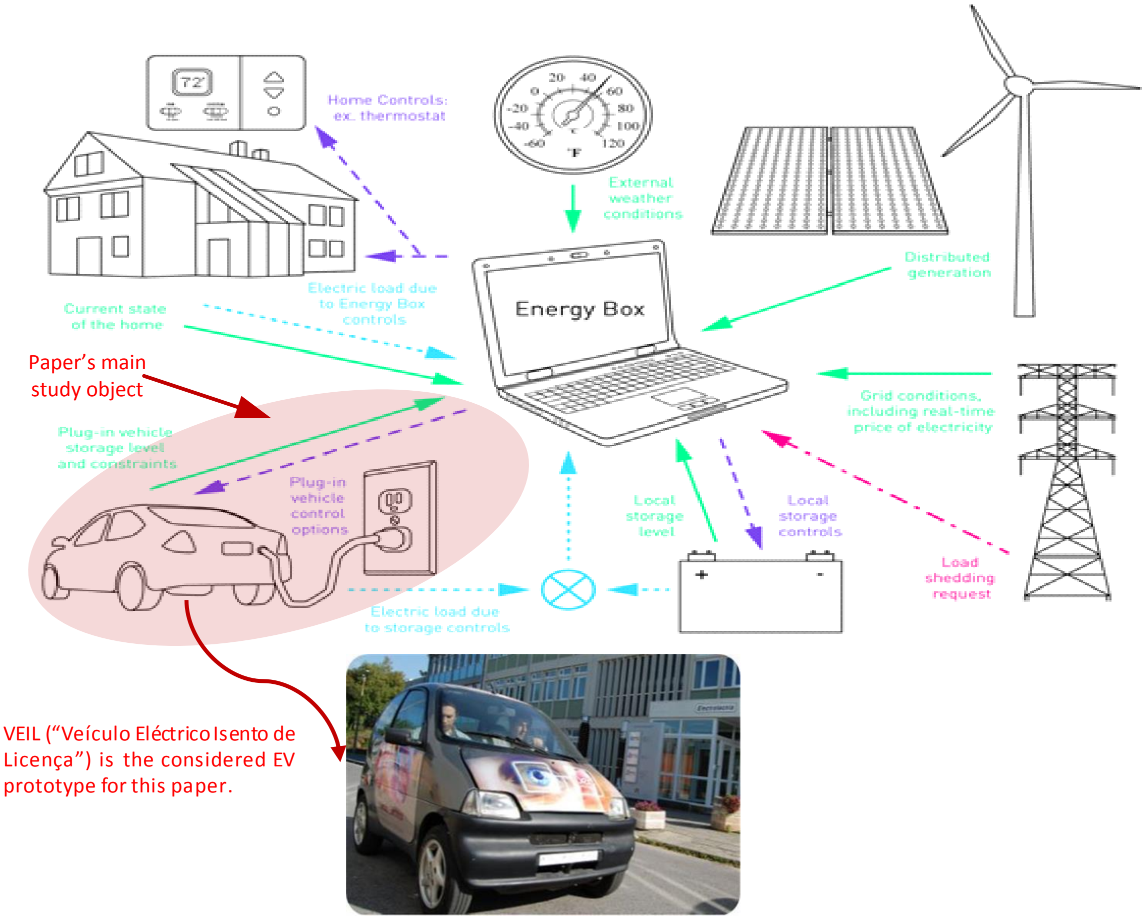


Figure 1: Energy Box concept illustration [6].

The current transformation of the electrical grid according to the smart grid concept generates opportunities for implementation of demand-side energy management systems technologies based on different pricing strategies that will allow a more efficient use of the electric power infrastructure. These strategies, already demonstrate that they are efficient in the application of electricity consumption alternative patterns. This kind of approach means benefits for the end users (e.g. reducing their electricity bill without degrading comfort levels) and for utilities as well (e.g. by the assistance that end users might provide in order to have better management of energy peaks, flattening the aggregate demand curve, and meeting supply with demand), leading also to environmental benefits [5]. Concerning EB technology, the most relevant aspect approached in this paper is the capability to manage the energy of one residential specific load, the EV. Thus, to obtain profitable electricity exchanges between end users and utilities, the EB will have the ability to store and learn about the end users profile. This allows taking cyclical decisions of storing or selling electricity from and to the grid, given dynamic variables such as, the price of electricity, weather conditions, comfort requirements, and electricity availability from decentralized renewable sources, without need human intervention.

In terms of command signal trades among utilities, end user's EB and the EV, a bidirectional communication system will be need. These involve communication devices, which will send and receive information signals about energy price, peak demand, reduce power demand curve and unused renewable energy. Then, according to the EV user cooperation capability and their respective storage energy or power supply capacity, can behave as a support system. With this technology, the decision about storage energy or selling electricity to the grid is based on the specific user profile and other dynamic variables. This is a quite interesting challenge that will require some sort of autonomous support based on decision support tools and adequate algorithms, where EV has a benefic and important role. Thus, technologies similar to EB are crucial for meeting the several opportunities and challenges offered by evolution through smart grids. However there is still needed investigation and pilot-projects in order to archive an energy management system of this kind [5].

Main Benefits and Drawbacks in End User and Utility Perspective

The G2V and V2G operation modes allow that all the EV can be seen as load, distributed energy storage system or as isolated electrical energy supplies. Thus, with a large EV and respective chargers integration (similar to the one presented in [8]) the electric grid will make possible the offer of several services which will differ in control regime, response time, terms of contract and price, having different benefits and drawbacks in the end user and utility perspective. Some of these services are related with peak power response capacity, storage for renewable energy, backup ability, peak shaving, spinning reserves and voltage and frequency regulation in order to improve quality service. One common benefit for each one of these services is related to energy acquiring possibility at the lowest prices, being the main drawback related to the still limited EV Energy Storage Systems (ESS) energetic capacity of [8] [9] [10].

Electric Vehicle Charger Characteristics

In order to accomplish the desired interaction between the EV and the EB, is important notice that the EV need to be associated a charger designed accordingly some specific features. Those are bi-directionality in power flow for charge and discharge operation modes (G2V and V2G respectively), capable of establish unit power factor and low Total Harmonic Distortion (THD) in order to not degrade power quality. The EV charger should also perform power control, have low construction complexity, if possible be classified as an on-board charger and be compatible with a regular 16 A plug. In order to fulfill these requirements the considered charger topology is the one presented and fully discussed in [8]. Regarding the battery technology, also in [8], are presented the considered battery pack characteristics. LiFePO4 is the deemed technology, because based on recent studies for energy storage systems applicability in EV, this is the most appropriate nowadays for EV powertrain purpose [11] [12].

ELECTRICITY TARIFF SCENARIOS

As previously mentioned, in near future demand-sensitive electricity pricing is expected to become the operative standard for energy tariffs mechanism. Since this paper intends to focus the importance and benefits of energy management technologies, mainly for the residential sector, is mandatory set all the pricing options in the end user perspective. Therefore, in this paper are considered three pricing methodologies presented in Table 1.

Table 1. Considered electrical energy tariffs.

Tariff	€/kWh
Simple	0,1418
Two Rate (peak period)	0,1674
Two Rate (off-peak period)	0,0878
Dynamic pricing (based on market)	Average hourly for week and weekend days

The two first methodologies, stated in Table 1, are designated as simple tariff and two rate tariff, being these established by "*Entidade Reguladora Dos Serviços Energéticos*" (ERSE) in 2013. The third is the dynamic tariff based on *OMIE* market prices (€/MWh) considering the access to networks tariffs, for each hour in January 2013 for Portugal [13]. To obtain the same price evolution to the end user, this hourly dynamic tariff was divided by a thousand in order to achieve an €/kWh relation. Lastly, this final daily electricity dynamic energy pricing was obtained by adding the access to grid tariff accordingly to the ERSE electricity price structure presented in Figure 2. The considered access to grid tariff value, was 0.0654 €/kWh for end users with power contracted under 20.7 kVA, accordingly to ERSE 2013's grid access tariff tables [14].

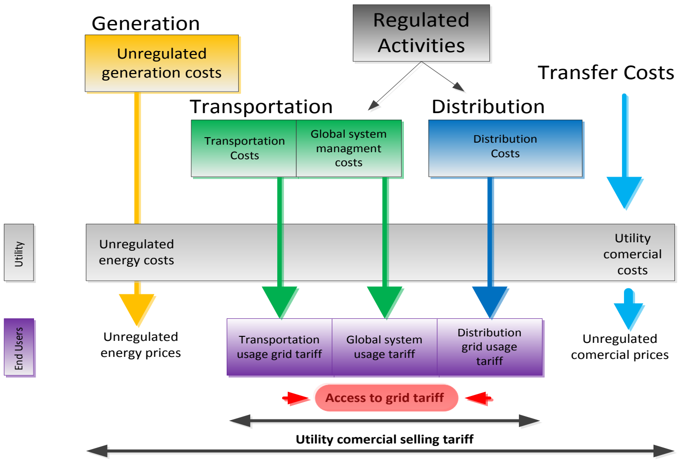


Figure 2: ERSE 2013 dynamic energy pricing tariff architecture.

In order to achieve more accurate results analysis, the 2013 January month was split into week days (twenty three) and weekend days (eight), being obtained two different dynamic tariff curves. These are the used price curves, for variable tariff case. These evolutions are the most updated electricity price values in Portugal for dynamic energy pricing, in order to obtain a less erroneous approximation facing the future of electricity market operation system.

In this paper is considered for the variable tariff, that each hour price is also the same for the utility to pay to the end users for their sold electricity. For the simple and two rate tariff is no admissible sell energy to the grid.

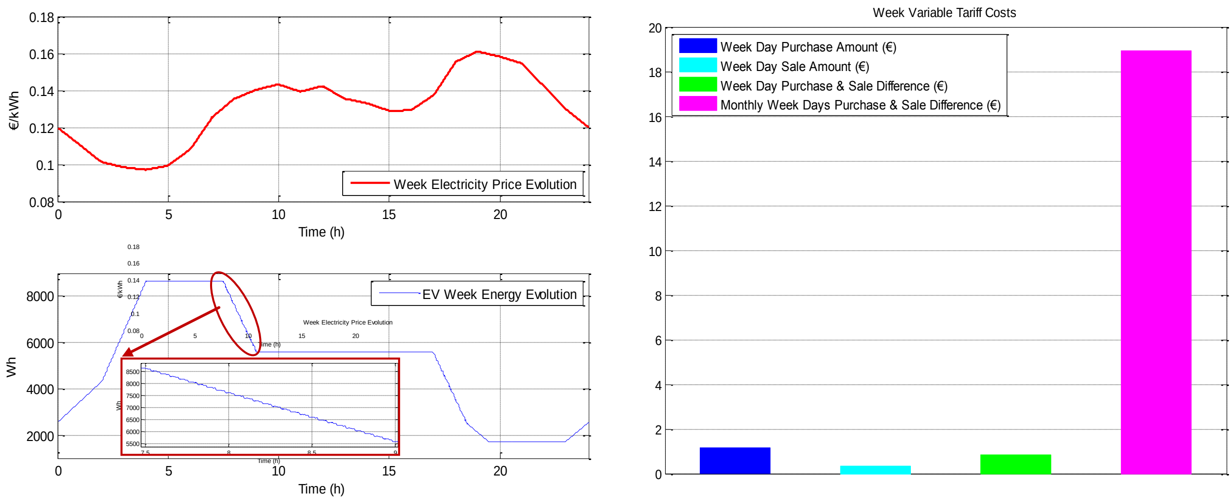
CASE STUDIES

This section introduces the approached scenarios in this paper. Four case studies will be next presented, where for each one of these, should be noted that the expectable life time conservation and safety levels preservation demands for 80% of the battery pack SoC utilization (for LiFePO4 batteries technology). The batteries operation temperature is considered constant (around 25ºC), and the proposed charger for this application ensures that the permissible voltage and current limits are not exceeded [8] [15]. Thus, for further understanding of EB possible decisions facing each scenario is a relevant remark that the maximum SoC level (100%) is equal to 8.640 kWh while the minimum (20%) equals to 1.728 kWh. For all presented scenarios it is considered that the EV is the family 2nd car, used at working days (week) for travelling and grid energetic exchanges participation, and at weekend days essentially for the grid energetic exchanges, being associated at one random residence.

The adopted strategy for buying or selling electricity is based on knowledge of the maximum and minimum electricity price along the daily 24 hours for each case. One third variable located between this maximum and minimum, will define the price slots for buying or selling electrical energy. Finally is established a linear relation between the current price and the power level applied in that instant, in order to valorize the flowing energy. Therefore, for the instants with the lowest and highest price, the EB will command purchase or sale operations respectively, using the maximum charger power level (2.3 kW), if none of the SoC limits is reached. For the further presented scenarios regarding the week days, the EV is daily out from home from 7:30 AM until 6:30 PM. Along this daily time slot, the first drive time period (expended time to get to work) goes from 7:30 AM to 9 AM, then the EV stays parked from 9 AM until 5 PM where energetic exchanges (charge or discharge) are not allowed. Finally, the end user daily trip back home takes 1.5 hours (like the morning period), arriving at home around 6:30 PM. In the driving periods was considered a typical routine for mobility in big European cities with low average speed and frequent start and stop situations, designated as ECE 15. These were used according the tests presented in [11] for a small EV prototype only with the considered battery pack as ESS and with regenerative breaking capacity. Thus, both 1.5 hour drive periods was formed by 27 times the ECE15 drive cycle, which corresponds to approximately 27.35 km, being the daily considered total journey distance of 54.7 km.

In this paper it is also important remark that only one EV is considered. Therefore, the grid impact of several EV simultaneously connected for charge or discharge purpose is not addressed.

The first case study approaches the considered dynamic energy pricing for the week days (see Figure 3). Through Figure 3 analysis, it is possible notice that the purchase and sale energy amount is defined according to the involved daily price slot, in order to valorize the EV storage energy and minimize the EV charging cost as previous mentioned. The variable for the price slot definition was approximately the mean value of this price curve (0.13 €, in this case). Thus, the EV energy evolution slope is bigger when the price is lower and is smaller when the price is higher for purchase and sale situations respectively.

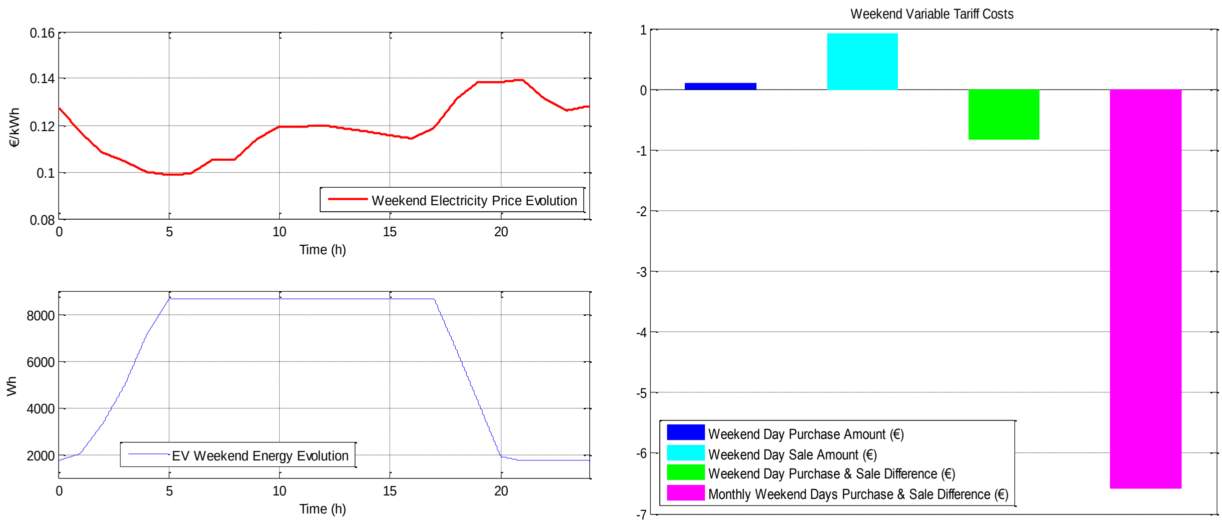


a) b)

Figure 3: a) Week days' electricity price and EV energy evolution. b) Dynamic energy pricing handling costs for week days.

As previously stated, for the week days from 7:30 AM until 6:30 PM is the daily time slot where the EV is out from home, therefore in this period exists energy consumption by travelling, as presented in Figure 3 a) zoomed area. In Figure 3 b) the handling costs are presented for the considered one week average day and the respectively total monthly amount, which is 23 (number of week days in January 2013) times the approximately 0.80 € value corresponding to the green bar.

In Figure 4 is presented the previous equivalent scenario analysis but for the weekend days.

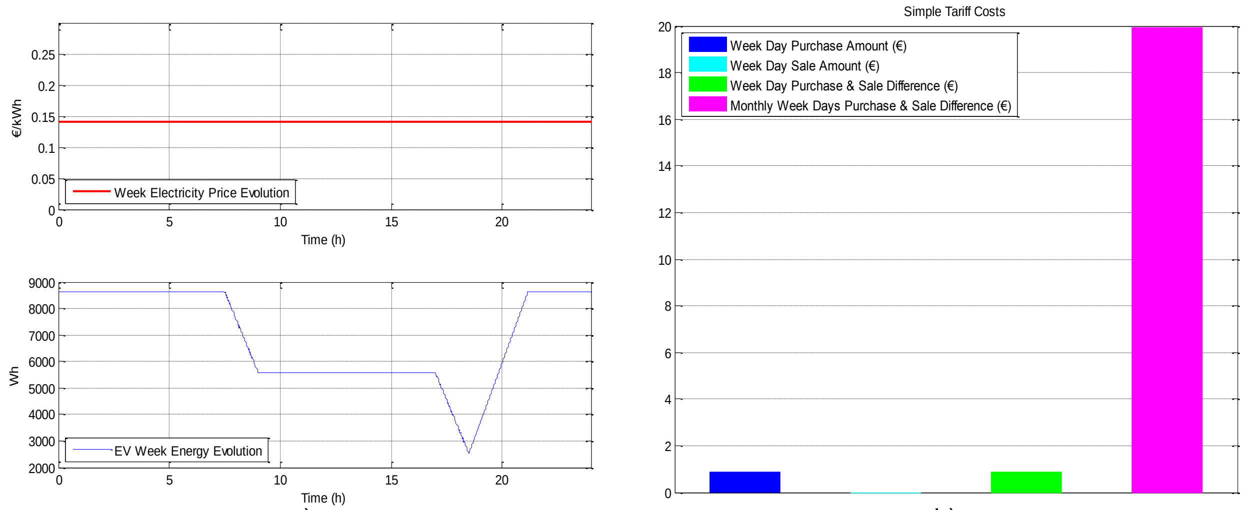


a) b)

Figure 4: a) Weekend days' electricity price and EV energy evolution. b) Dynamic energy pricing handling costs for weekend days.

Therefore in Figure 4 a) the purchase or sale energy price slots were defined using as reference value 0.12 €. This possible EB decision means to purchase electricity when the price was approximately under 0.12 € and only sell it back around 7 PM which is the beginning of the day period where the electricity price is higher. Thus, this is one possible decision in order to maximize the profit, being the monthly handling cost around 7 €. Notice that when the energy sold is higher than the purchase amount, the obtained difference between both is negative, which means profit in the end user perspective.

In Figure 5 and Figure 6 are presented the simple and two rate tariff scenarios respectively. For these, selling electricity back to the grid is not permissible, being only considered the January 2013 week days (23 days). As is possible notice, in the presented cases the EV fully charge level is attained before the end of the day, being minimized the partial or minimum SoC level time in the battery pack, which also increasing their life time expectance. Figure 5 presents single tariff scenario based on stated values in Table 1.

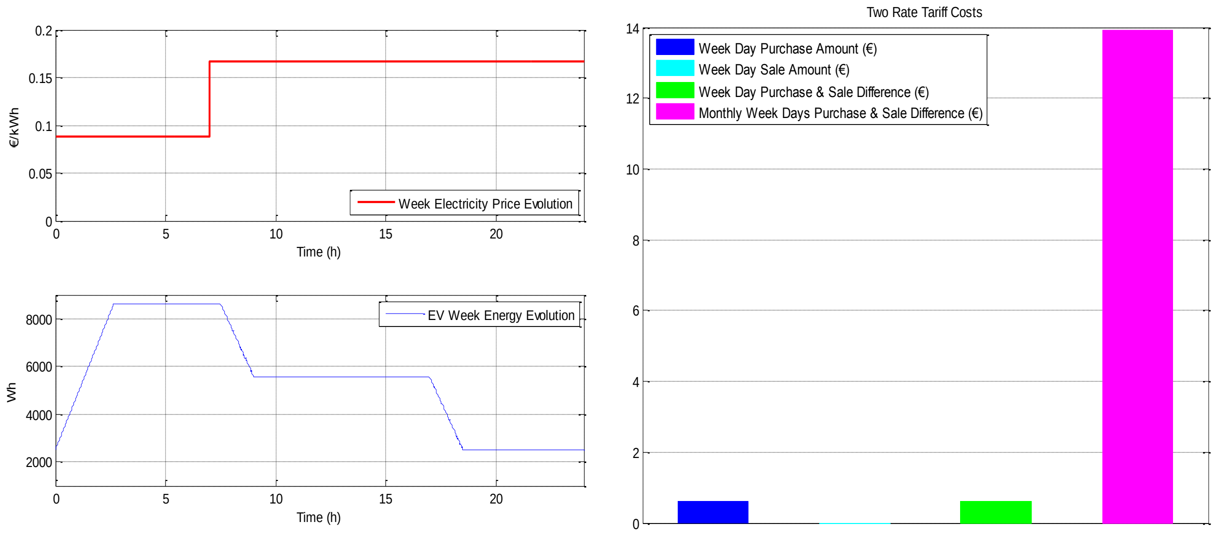


a) b)

Figure 5: a) Week days' simple tariff electricity price and EV energy evolution. b) Simple tariff handling costs for week days.

Through Figure 5 analysis and considering what was previously stated in this paper, is understandable the lack of sold energy amount, and the high monthly expended amount for EV charge purpose. In fact, is only possible buy energy following a constant and high price level when compared to the other case studies.

Figure 6 presents the two rate tariff scenario based on stated values in Table 1.



a) b)

Figure 6: a) Week days' two rate tariff electricity price and EV energy evolution. b) Two rate tariff handling costs for week days.

In the two rate tariff, the most profitable EV charging period is from 0 AM to 7 AM, which is the off-peak period having the lowest electricity price among all presented cases. Once is achievable a meaningful difference price between the peak and off-peak period, the EB decides to charge only in the off-peak, because that time slot is big enough for fully charge the EV before the beginning of the drive period, being minimizing the EV charging cost.

The final overview facing all presented scenarios is made through Figure 7 analysis.

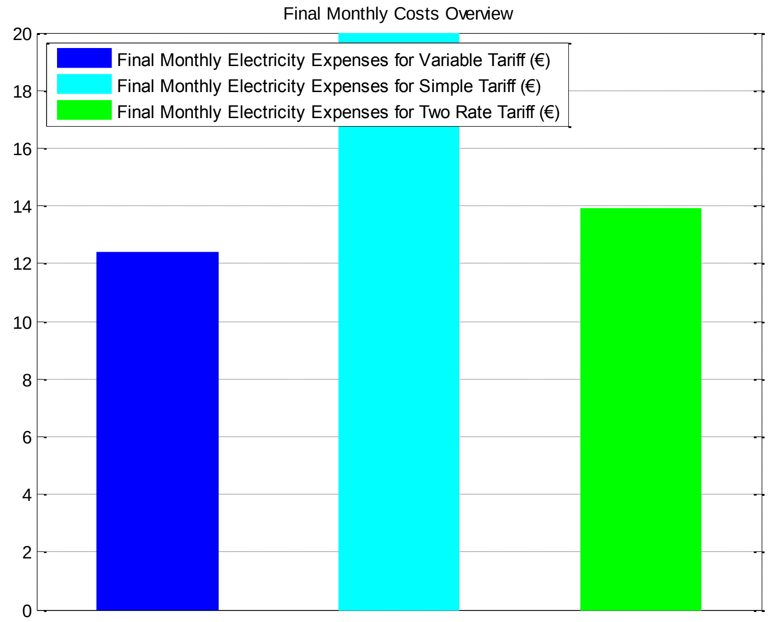


Figure 7: Final monthly handling costs for each approached tariff method.

In this figure are summarized all final monthly EV electricity expenses amounts for each considered case. The final variable tariff value is obtained by the sum of the monthly total amounts for the 23 week days and the 8 weekend days which totaling the first 2013 month. Obviously the other two case studies concern the simple and two rate tariff, being understandable their final bigger values. Thus in this cases is not possible sell back to the grid the EV storage energy and average electricity price value is higher than in the variable tariff case. The final two rate tariff monthly cost is close to the variable one due to the EV charging was performed in the off-peak period where the price is lower.

CONCLUSIONS

This paper tackles the end user achieved benefits in the exchange of electrical energy with the utilities concerning one EV. This is a dynamic process managed by autonomous support technologies like EB devoted to residential sector where the EV is approached as a load or supply identity. Thus, the EV may have a prominent role when associated to autonomous residential electricity management systems like EB, being mandatory to have associated EV chargers with specific features, which are fundamental for a more sustainable energy system.

Through the presented results analysis and authors considerations it was possible to conclude that the future of electricity dynamic energy pricing associated to the EB and EV technologies could allow to end users archive important monetary benefits. Hereupon, a good trade among EV energy needs given the electricity prices is always attained. Thus, among all presented case studies the dynamic tariff case associated to the mentioned technologies is the most profitable being its monetary profit of 7.6 € and 1.5 € when compared to the simple and two rate tariffs respectively. If we consider twelve equal months like the approached in this paper, one single end user will achieve approximately 91 € and 18€ of annual profit, given the previous presented comparison.

Due EB decisions for minimize the charging cost and maximize the sale price, the end user always obtains good tradeoff in the energetic exchanges. The fact of the charger being power “flexible” allows performing charge/discharge with different power levels, which benefits the power distribution among all domestic loads. The end user also has the advantage of not need to concern about price scheduling since the EB takes the better decision for him, he just needs to plug the EV once he at home.

It should be noted that in all of these cases and presented results several capabilities and characteristics of EB are not being taken into account, such as crossing power requirements of the other domestic loads or taking decisions in order to a specific user profile. Exploiting all the potentialities of EB technology is not the objective of this paper. The developed study cases were based on real energy price approximation, real battery technologies restrictions and logical random end user decisions concerning EV needs and price evolution, just to demonstrate what could be the end user economic benefits.

Thus, the controllable EV's charger under EB decisions will be crucial in the future of residential energy trades, being archived significant profits which leads to optimized energetic handling cost.

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Italian Financial and Energy saving policies: Cost-Benefit Analysis based on the Enea Reports issued within the survey span 2007-2010

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Abstract
The aim of the present research is to assess the cost-effectiveness of mixing and combining different energy retrofit measures for the several geographical areas of Italy. The research work is based on the analysis of the results supplied by the several Reports drawn up by ***ENEA*** - the ***Italian National Agency for New Technologies, Energy and Sustainable Economic Development*** - year by year since 2007. The work is centered on finding out a criterion, based on simple and available data, that is able to identify the most cost-effective retrofit measures to improve dwellings' energy efficiency.
With the final objective of adjusting and addressing the subsidies and the policy makers' decisions in the most profitable way, there were developed some comparative cost-effectiveness analyses and there were highlighted the most consistent kinds of renovation, both with the current economic outlook and depending on the specific geographical and climatic background.
This paper presents and discusses the consequences of the Italian government leaders' policies and purposes of reducing the energy demand in the residential sector, in order to facilitate the development of a consistent plan and extention of public incentives and tax deductions for dwellings' energy-saving retrofits.
Thence, it's designed to represent a reference point to help decision-makers and relevant stakeholders appreciate how targets have been used till now and how effective they could be, also providing evidence to be used in the upcoming policy development discussions.
Actually, as this paper proves, the earlier outcomes connected with the current National Energy Strategy reveal that some such adjustments and refinements are needed, in order to make it really effective and worthwhile.
Although the praiseworthy initiative and aim that underlies such a political-economic venture, it shows several gaps and faults that should be offset and filled up.

Nomenclature
OO: Opaque horizontal surfaces' insulation (floors and roofs);
OV: Opaque vertical surfaces' insulation (walls);
IN: Replacement of windows with low transmittance ones;
ST: Installation of solar thermal collectors;
CI: Replacement of boilers with condensing or biomass ones or with high efficiency heat pumps;

NW: NorthWest Italian macro-area (Piemonte, Valle d'Aosta, Lombardia, Liguria);
NE: NorthEast Italian macro-area (Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, Emilia-Romagna);
CE: Central Italian macro-area (Toscana, Umbria, Marche, Lazio);
ME: Southern Italian macro-area (Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria);
IS: Islands Italian macro-area (Sicilia and Sardegna).

Introduction
The present research-work is a report and a review of the most representative financial instruments introduced in Italy since the enactment of the Finance Act 2007 (and its successive 2008 and 2010 edition), i.e. the Fiscal Incentives for Energy Savings in the Household Sector (a.k.a. "The 55% Tax Reductions for Building Retrofitting") .
It is in particular focused on those only kinds of building renovations related to the three last Commas (i.e. 345, 346 and 347) of the First Finance Act Article, that were carried out in private dwellings within

the time span of 2007-2010. With reference to the several Reports drawn up by the ENEA in order to relate the Authorities about costs and results of the above incentives, there were written and filled out different spreadsheets, schedules and graphs to collect and sum up all the data and information that could be the most significant to define an all-embracing cost-benefit assessment.
The main purpose of the present research is in fact aimed at the assessment of the results till now obtained in terms of their cost-effectiveness, resting on an amount of data large enough to take stock of the early stages of the Government Campaign.
Thanks to that it could be possible, in the foreseeable future, to adjust the Italian Energy Policies and address the politicians' decisions in order to encourage those kinds of renovation, where they should be more cost-effective, and instead give up and/or limit such a financial support, whereas some other interventions reveal their lacks and disadvantages.
Actually, the rising energy costs, the growing concern about environmental issues and the approaching exhaustion of world energy resources are urging the whole European Community and the several National Governments to improve their energy management.
With European overall policy being to significantly decarbonize its economy by 80% to 95% by 2050, the building's sector, which accounts for 40% of the region's energy consumption and almost the same level of GHG emissions, must undoubtedly play a key role [5].
And any strategy to tackle the challenge in the buildings sector will clearly require a significant amount of financial investments and therefore long-term political commitments.
Hence, the main goal of the present work is to gather key facts derived from the use of some such financial instruments as the next steps in improving the energy performance of buildings: this paper would like to show the Italian tax reliefs already in place and points out the main observations related to the impact of such a policy in an all-embracing assessment.
In general, a particular attention is usually paid to Public Administrations, as European and National Legislations often point out that these entities must provide energy efficiency measures, as well as for the reasons above indicated, also in order to represent an example for the entire community and for the citizens too [6].
But it's very important also to find out how to foster and encourage energy efficiency improvements and energy saving measures in private dwellings, in order to achieve the double advantage, both to reduce the global energy consumption level within the private sector, and to increase investments favouring the creation of additional cash flows too.
"Buildings are at the centre of our social and economic activity. Not only do we spend most of our lives in buildings, we also spend most of our money on buildings. The built environment is not only the largest industrial sector in economic terms, it is also the largest in terms of resource flow" [7] .
Hence, the possible combination of some such multiple benefits makes the building sector a crucial field for policy makers at EU and national levels. Therefore, a policy framework that can support the national markets in unlocking these potentials is strongly needed.
And moreover, most of the previous, several researches already developed, demonstrate that financial and environmental aims are not necessarily a contradiction, but can actually support each other [8].

The background of the previous knowledge and the potentialities disclosed by this paper

There were already depicted, at European International level, various reports and surveys that have taken a closer look at how financial instruments are currently being used in Europe, providing some evidence of their effectiveness too [5,10,17]. In particular, they have underlined a great variety of financial instruments available throughout the EU to support the improvement of the energy performance of buildings, but, although their undoubtable relevance, none of them has analyzed into details the respective implications at a "single-nation-level". As a matter of fact, this particular topic isn't thoroughly discussed, neither in scientific literature, nor in specific technical guidelines: thus, the example offered by the ENEA Reports could represent, at a national level, a very important instrument to develop a concrete strategy with the aim of creating some guidelines to optimize and address the challenge of renovating the existing building stock, keeping also pace with the ambitious aims of both the Italian Nation and the European Union.
Actually, all the data on costs and energy savings collected through the last four years by the ENEA and provided by such reports, represent a valuable source that should be used systematically to evaluate the financial policies' current approach and to give some guidance on the future. And moreover, since achieving energy savings in buildings is a complex process, policy making in this field requires a meaningful understanding of several aspects and characteristics of the building stock:

reducing the energy demand involves the deployment of effective policies which, in turn, make it necessary to understand what affects people's decision making processes, the key characteristics of the building stock, the impact of current policies etc…

As already mentioned in a recent article [9], many other authors have already pointed out that there are many obstacles to the spreading of good practices. One of the main problems is the cost-effectiveness of home energy retrofits that is rarely taken into account in national policy programs [27].

In particular, the literature review highlights some critical issues:

- National legislation can be too strict and prescribe energy efficiency requirements that make retrofits cost-ineffective for homeowners [22, 25];
- Energy price is fictitiously low because social costs of production are often hidden and not charged directly on users' bills [23, 24, 26, 27];
- Uncertainties on future energy price make the economic feasibility analysis of works really difficult [19, 20];
- Public subsidies are necessary to reduce payback time and increase economic benefits for investors [26, 27].

Taking account of some such remarks and focusing the attention on Italy and on its own financial policies and energy regulations, it reveals very important (after due considerations related to the previous, early stages of the public incentives established till now) to plan and address the future energy policies so them to be consistent and profitable.

Therefore, the Enea Reports and their analysis in depth could play a fundamental role to understand which and where some kinds of buildings' renovation reveal their cost-effectiveness (and thence should be encouraged with a suitable financial support), and when instead they display a lower all-embracing consistence.

The *ENEA REPORTS*: the so-called reports consist in all the information and data collections drawn up by the *Italian National Agency for New Technologies, Energy and Sustainable Economic Development* in order to test and assess the effectiveness of Italian laws and regulations related to the "55% tax reductions" for building retrofitting in Italy [1, 2, 3, 4].

The above reports were issued, year by year since 2007 (i.e. since the earliest incentives settled by the Finance Act of 2007), in order to monitorize the results of the financial policies adopted in Italy to increase the Nation's energy efficiency. They involve the entire country and, splitting it into 5 different geographical macroareas, allow to carry out an investigation and to develop an analysis centered both on the single macroarea's level and on the whole Italian level.

In line with the EU general objectives, and most of all in the light of both the recent 2006/32/CE and the 2010/31/CE Directives' enactment, besides the so-called *EU 20:20:20* energy saving planks, the primary goal of the Italian energy policy concerns the implementation of several measures addressed to liberalize and increase the overall efficiency of the energy sector [10, 17].

And in order to align with the above mentioned European policies and objectives, the Italian Government has in fact adopted a strategy aiming at the diversification and the penetration of new energy forms in power generation, with a concurrent improvement of energy efficiency and conservation in end uses, as well as with a wider eploitation of renewable energy sources.

Thence, on the one hand it is attempting to incentive mechanisms and methodologies for quantifying energy consumptions and energy savings in dwellings, and on the other hand, since the Finance Act issued in 2007 and in order to increase energy savings for winter heating in existing buildings, has established a system of generous financial incentives: they allow a tax deduction of 55% for all the investements sustained both by private, individual citizens and by companies.

Description of the method used

"If you cannot measure it, you cannot improve it "(Sir William Thomson, Lord Kelvin) [10].

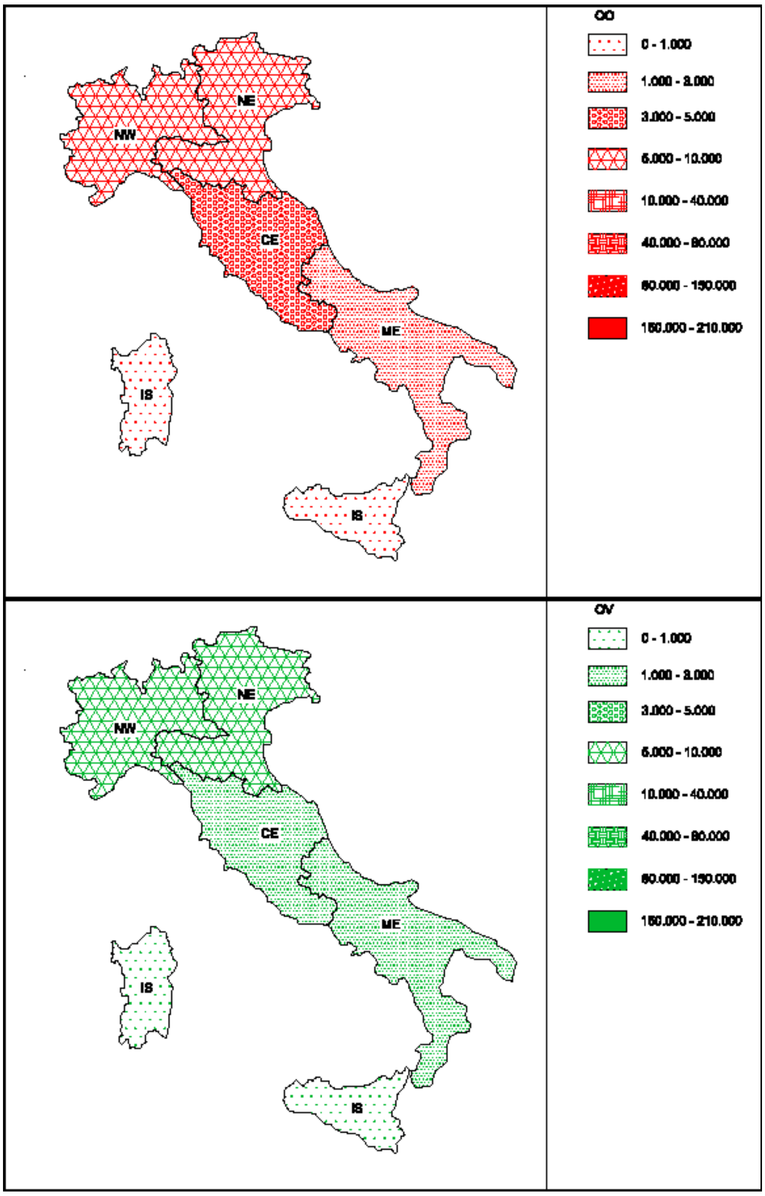
The present analysis has been based on all the all the statistical data provided by the several Enea Reports issued in these latest four years. Actually, the above data consist in a huge set of statistical information related to the following main and most significant key-elements: the number of different kind of renovations respectively realized in the several italian macroareas, their relative average costs, and the consequent energy savings (and economical benefits) achieved. After the initial scanning and collecting of the most relevant results summed up by the reports issued in 2008 (based on the 2007 Energy Campaign results), 2009 (based on the 2008 results), 2010 (related to the 2009 Campaign) and 2012 (based on the 2010 results), there were in fact filled up several resume schedules, drawing the respective graphs and summary tables, in order to follow and outline the evolution and the statistical changes within the whole timespan analyzed (as below detailed). All the

assessments were carried out through excel, hand cost-benefit calculations and spreadsheets, and were developed basing such analyses on those which should be the most suitable lifespan values for the different kinds of intervention: thence, after a global review of the current European Standardization and of the Regulations related to this topic, there were introduced some adjustment factors which, due to the statistical nature of all the data processed and being the typological range of such renovations so wide and general, were assumed quite "widespread and global-fitting".
There were adopted the following reference intervals: 50 years both for the horizontal and vertical surfaces insulation (i.e. walls, floors and roofs), 30 years for the windows' replacement and 25 years both for the solar thermal collectors' installation and the heating plants' replacement [11,13,16].

Table 1: Number of renovations registered by Enea in the several Italian macroareas within the time-span 2007-2010

2007						
	NUMBER INTERVENTIONS 2007	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
	OPAQUE HORIZONTAL SURFACES INTERVENTION	413	472	280	119	52
	OPAQUE VERTICAL SURFACES INTERVENTION	674	932	379	188	53
	WINDOWS FRAME REPLACEMENT	13.868	10.263	5.410	2.863	935
	SOLAR PANEL INSTALLATION	3.341	8.899	3.180	978	2.661
	THERMAL PLANT REPLACEMENT	9.620	9.564	5.756	2.068	563
2008						
	NUMBER INTERVENTIONS 2008	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
	OPAQUE HORIZONTAL SURFACES INTERVENTION	2.339	2.518	916	341	139
	OPAQUE VERTICAL SURFACES INTERVENTION	1.221	1.690	285	227	62
	WINDOWS FRAME REPLACEMENT	42.915	28.484	16.972	9.731	3.306
	SOLAR PANEL INSTALLATION	6.691	16.525	6.484	2.480	4.417
	THERMAL PLANT REPLACEMENT	21.563	21.999	12.543	4.124	1.487
2009						
	NUMBER INTERVENTIONS 2009	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
	OPAQUE HORIZONTAL SURFACES INTERVENTION	4.331	3.440	1.481	407	179
	OPAQUE VERTICAL SURFACES	2.133,00	2.283	438	385	138

	INTERVENTION					
	WINDOWS FRAME REPLACEMENT	48.735	32.777	18.741	10.632	3.921
	SOLAR PANEL INSTALLATION	9.383	15.771	5.664	2.079	3.042
	THERMAL PLANT REPLACEMENT	25.120	23.800	13.209	5.983	2.650
2010						
	NUMBER INTERVENTIONS 2010	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
	OPAQUE HORIZONTAL SURFACES INTERVENTION	2.338	2.555	880	316	145
	OPAQUE VERTICAL SURFACES INTERVENTION	1.570	2.067	493	347	113
	WINDOWS FRAME REPLACEMENT	94.503	62.986	36.208	20.058	7.654
	SOLAR PANEL INSTALLATION	14.527	19.542	7.494	3.088	3.060
	THERMAL PLANT REPLACEMENT	48.079	43.890	20.232	9.429	4.053


OO
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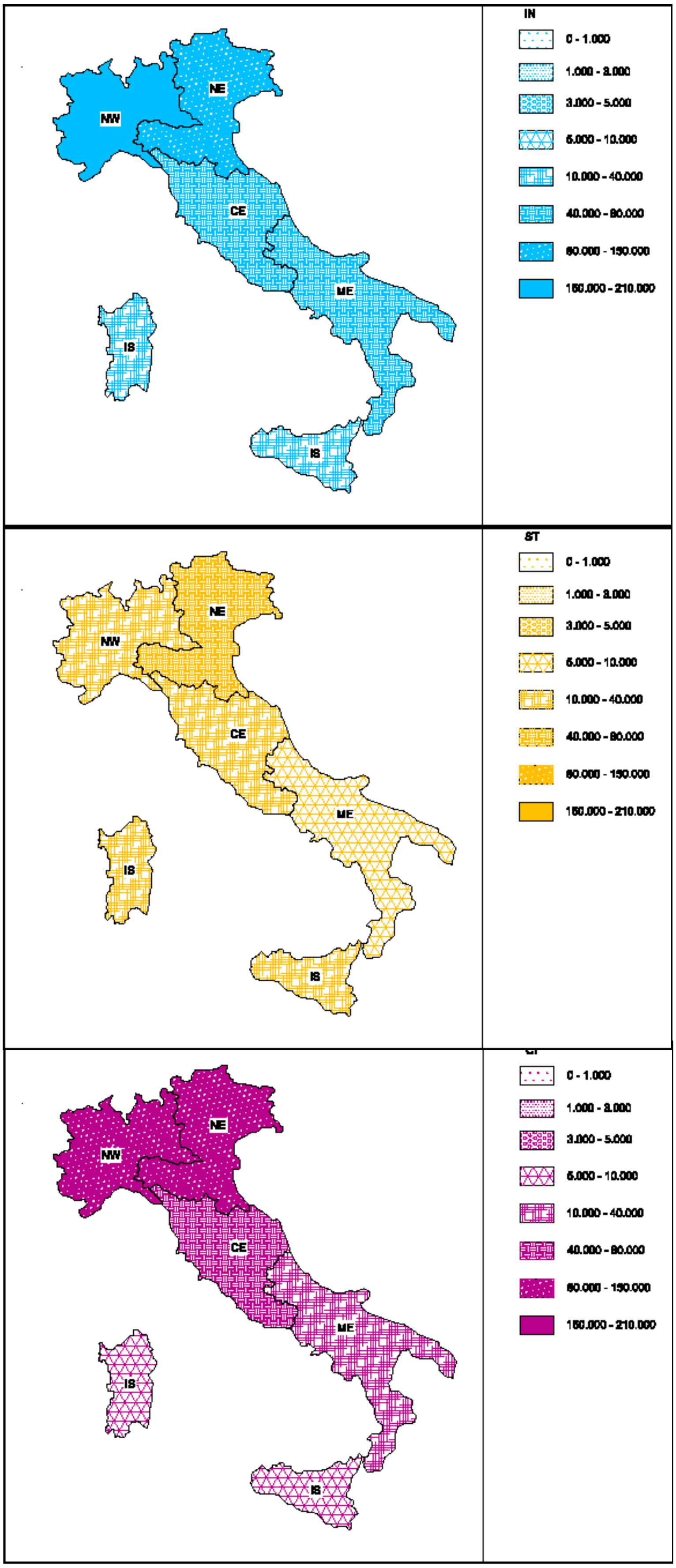

Fig.1: Time-span 2007 – 2010: Cumulative overall renovations' distribution along the whole Italy

As it's easy to note, there are a lot of differences and discrepancies among the several resume tables and the figures above shown, both related to the number of renovations registered along the entire country, and to their respective distribution. First of all, an evident gap is recognized between the global number of renovations reported during the first campaign year and the successive ones. And such a statistical phenomenon is essentially ascribable to the following main reasons: on the one side, it is due to the first venture's year being such an "initial, testing experience". Thence, despite the awareness campaign and the Enea's Helpdesk and informative venture, people hadn't enough experience with such an investment plan yet. On the other side, an error had occurred in the earliest version of the Budget Law issued in 2007 (and hence in the consequent so-called "Decreto Edifici"): due to an editing and drafting mistake, the U-Value, thermal transmittance limits to be respected in realizing the different kinds of opaque horizontal renovations, there were in fact reversed. Thence, one more reason that has made even fewer the already low rate of such a quite expensive kind of building's retrofit.

Research Results and Discussion

Also in the light of the above considerations, it's important to underline the difficulty of globally implementing a meaningful, exhaustive and fair comparison among all the different yearly reports analyzed. Beside that, a further alteration and data corruption that affects this global trend overlooking is made up by the sensible differences in the population's amount - and thence in the dwellings' number - among the different macroareas scanned (and above of all, in the case of Islands Macroarea).

Table 2: Cost-Benefit balance values reckoned for the several Italian macroareas within the time-span 2007-2010

COST-BENEFIT BALANCE SUMMARY 2007	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
OPAQUE HORIZONTAL SURFACES INTERVENTION	42,43	**35,82**	45,47	79,35	52,18
OPAQUE VERTICAL SURFACES INTERVENTION	54,10	47,15	57,56	72,34	126,02
WINDOWS FRAME REPLACEMENT	95,54	92,94	115,68	163,54	172,33
SOLAR PANEL INSTALLATION	78,90	68,70	59,72	37,93	37,79
THERMAL PLANT REPLACEMENT	35,92	45,72	46,98	60,93	73,45
COST-BENEFIT BALANCE SUMMARY 2008	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
OPAQUE HORIZONTAL SURFACES INTERVENTION	32,53	32,13	49,72	71,83	99,82
OPAQUE VERTICAL SURFACES INTERVENTION	42,11	38,22	54,62	62,86	98,72
WINDOWS FRAME	113,64	103,33	153,81	243,47	232,14

REPLACEMENT					
SOLAR PANEL INSTALLATION	44,95	50,72	30,24	**14,04**	15,72
THERMAL PLANT REPLACEMENT	34,97	46,82	42,31	43,12	57,45
COST-BENEFIT BALANCE SUMMARY 2009	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
OPAQUE HORIZONTAL SURFACES INTERVENTION	32,22	35,53	44,37	61,92	80,96
OPAQUE VERTICAL SURFACES INTERVENTION	42,50	37,27	59,12	58,75	108,55
WINDOWS FRAME REPLACEMENT	116,72	105,23	142,66	188,65	214,81
SOLAR PANEL INSTALLATION	52,24	52,37	31,01	**23,34**	24,49
THERMAL PLANT REPLACEMENT	42,89	52,19	44,55	68,82	68,58
COST-BENEFIT BALANCE SUMMARY 2010	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
OPAQUE HORIZONTAL SURFACES INTERVENTION	33,12	41,46	58,70	79,35	85,56
OPAQUE VERTICAL SURFACES INTERVENTION	46,86	53,71	76,63	88,99	103,15
WINDOWS FRAME REPLACEMENT	106,19	98,06	136,33	167,53	197,53
SOLAR PANEL INSTALLATION	67,79	60,93	54,09	28,42	**23,58**
THERMAL PLANT REPLACEMENT	55,93	74,93	86,59	94,45	108,35

The overall frame depicted by the above table confirms what right now outlined and provides much further, very interesting food for thought and research questions to delve into: first of all, it's important to appreciate the big effort required by such a survey and data gathering. Beside that, also the main aim and intentions which led this global campaign play a strategic role to realize the broad sweep and the weight of such financial and energetic policies, with the final target to improve and refine them.

And although the trends' analyses and data-processing implemented by the above cost-saving ratio values actually don't directly supply a clear indication about how to address and develop a future, worthwhile financial policy and investment plan, they reveal themselves fairly meaningful.

The cost-benefit balances were assessed, year by year and for all the several Italian macroareas, through the evaluation of the ratio between the weighted average cost (i.e. the actual average cost, given in €) and the weighted average energy saving (expressed in MWh per year) calculated for any kind of renovation, also considering the respective LCC factors before introduced.

Actually, those data provide a global frame quite patchy and uneven and, at first sight, could be seem affected by some such mistakes and/or evaluating errors.

But a deeper analysis and a careful examination of the boundary conditions and global background that lay behind that lead us to some reasonable comments and observations.

Beside the already highlighted appreciable differences in the population's amount and in the dwellings' number of all the macroareas, another reason of such a relevant results' gap and mismatching is ascribable to the substantially different economic conditions which make the northern areas more active and resourceful.
And a further element which doesn't help the survey to find out a global, common analyzing criterion and that concurs to such a result is closely connected to the distinct weather patterns that concern the entire Italy.
Actually, the whole nation involves a quite wide range of different Climatic Zones: 6 exactly - from the A Zone, till the F Zone - and thence 6 distinct weather contexts and environmental backgrouds.
But, despite all the above considerations, such a huge amount of data and informations however plays a very important role.
And although the earliest results till now outlined reveal themselves so much heterogeneous, it could reveal possible and quite worthwhile to base on them a final knowledge and an overall comprehension of which and why should be the most cost-effective kinds of renovation for any Italian Macroarea.
Thence it would be also easier to find out the most profitable adjustments and optimizations that should be applied to the already issued financial strategies.
However, it should also be remarked that, since all the previous years' analyses didn't allow us to detect any significant and reliable prediction or trend to base on and to develop the future steps of the research, it could be possible only work out some few, very rough assumptions to lead the work.
For example, it could be possible gathering that, in the future and with some such further technical developments, the average cost of the different energy saving solutions should decrease, but on the other hand, some new technologies are going to be probably developed and should increase and vary also the inflation rate, the interest rate and the price of money…
Moreover, although the ongoing global climate changes, the southern Italian areas are actually in general more warm and with a wider solar radiation than the rest of the country; but, besides the above considerations, we don't have any mathematical certainty regarding the future, unless the information and the data already collected.
Also the latest, lowest cost-benefit ratio value registerd in the Islands macroarea for solar panel installations (23,58) confirms the appropriateness of such an already registered trend, while it should be strongly recommended to enhance and encourage the solar thermal collector equipments in the south of Italy (due to the other two, lowest ratio values reckoned of 23,34 and 14,04).
But another, really important and more precise information is needed with reference to the already issued financial strategies and, most of all, in relation both to the current and to the incoming tax reduction criteria.
While it would be necessary to adopt a far-sighted policy in order to allow, in the future, such facilitations during a wider time-span, a lot of care is needed in order to plan them avoiding unfruitful investments.
Restrictive upper limit should be settled, also exploiting all the earliest cost-effective information already carried out. Moreover, turning towards both the latest, urgent European statements and Regulations, and towards the overall economic crisis, the standard-range to be respected in order to obtain such fiscal reliefs should be stiffened.
Thence, just related to the above last topic, it clearly turns out to be a suitable decision the hardening of U-value limit ranges to be respected along the different macro-areas, while it should be avoided the incoming decision to make no more binding the energy efficiency certification proofs for most of the kinds of renovation - i.e. with reference to windows' replacement, solar panel installation and thermal plant replacement.
On the other hand, it should be recognized that right this last kind of energy retrofit, in spite of its higher cost-benefit ratio value and thence its flimsiness, is also the most affordable measure (from an economic point of view), besides its most quick and easy feasibility.
Hence, recalling that a National Policy and Energy Strategy could be really worthwhile if enough balanced and widely exploitable by a large users' bracket, a reasonable and fairly-weighted financial support should be preserved also into boosting such outwardly fruitless type of renovation.

Conclusions

As this work shows, the building sector - and above all the residential private dwellings - can significantly contribute to mitigate and smooth over the ongoing climate change, while delivering many other social benefits too. Political courage and initiative, innovative investement tools, together with a

social awareness, are the real key factors that could contribute to a radical trasformation and improvement of the whole sector.
Thence, the already existing EU policies - and in this case the Italian financial programmes - should be implemented in a best practice manner in order to achieve the intended energy savings, while on the other side some new instruments are strongly needed to stimulate a deeper renovation wave across the entire country [5,16,17].
But another fundamental challenge is represented by the observation that good policy making requires a good knowledge about the *status quo* of building performances and thence, to contribute to the success of its main goals, it will be also necessary plugging some relevant gaps that make it difficult to develop targeted programmes, to monitor policy's implementation and to evaluate its progress.
Thus, the principal actors of the whole process should strongly invest all their efforts into fill up these data gaps, harmonizing the entire monitoring, reporting and evaluation process, in order to provide for the best resolutions.
On the other side, it's important to underline that, although these targets are fundamental, they should be definitively seen as only one among all the other elements that make up the global solution.
Only thanks to an all-embracing assessment it will be possible attending to a relevant renovation opportunity, both innovating products and services and building a well-functioning energy saving renovation market. Thence it will be also possible to offer at the same time attractive solutions to private and commercial customers, as well as making the highly efficient buildings a common standard for the entire Italian building stock.
Moreover, recalling the main goals and purposes that have led the earliest analysis, the future steps of such a work will be focused on the single study of all the several Italian Macroareas - one by one - in order to find out how it could be possible to define the future energy-saving strategies, refinining and calibrating the results already achieved.
The above process will be planned both in function of the previous results and the respective different climate conditions, and will involve a full exploitation of the linear programming analysis potentialities, implementing in particular the Dantzig's simplex method.

Future Outlook

As already intended and set out to do, the future studies would proceed and go on starting from the data and sentences already available and will be based on the same life-span ranges already assumed for the different kinds of renovation, but will also resort to such more advanced algorithms and calculation technics than the simple spreadsheet-hand computations.
And also in the light of the ongoing political financial strategies and policy makers' statements (which will globally involve an investment valued at around 180 billions of Euros till the year 2020), the main research goal to find out and encourage only the most cost-effective kinds of building retrofit has been confirmed [18] .
Moreover, the Italian Revenue Agency has recently published the New *"Guida sulle Agevolazioni Fiscali per il risparmio energetico"* (the New Guide about how to join the 55% Tax Deduction for energy-saving renovations). Since the Decree n. 83/2012 has been definitively approved by the Italian Government and transformed into the Law n.134 - 07/08/2012 - the 55% tax deduction has been extended until the 30th June 2013 while, with effect from July the first 2013, the 55% tax cut will be replaced by the normal 36% tax deduction provided for generic buildings' retrofits which, since the year 2012, had become definitively structural and never-ending.
And the most important aspect to underline with reference to the last proof of the *"Strategia Energetica Nazionale – National Energy Strategy"* is referable, besides to the lengthening of the 55% tax deduction, to the tax cut differentiation based on the real and concrete benefits renovations-related. They are also going to play a fundamental role into the future banks' plans of innovative, financial and contractual models focused on such a feature.
But on the other side, it's also important to observe that, as well as it happens in almost every context, a balance should be reached between the ideal and most profitable actions to plan and the real economic background of the people middle classes to deal with.
Whilst a different, best-fitting binding target is needed in order to address the future policy makers' statements, the risk that it would limit a certain flexibility of response should be recognized.
Furthermore, a binding target should be linked to a harmonized measurement method; but this should be both robust and flexible so that stakeholders have enough confidence that it will enable the demonstration of all the consequent, achievable progresses.

Such targets are very important in galvanizing action and understanding progress, but they also have to tread a fine balance between achievability and ambition [10].
They must be founded upon need and evidence of the energy saving potential, moderated by real-word expectations (in addition to economic and technical considerations) of what can realistically be achieved, as well as upon the progresses that can be credibly and transparently shown.
Undoubtedly, there will be necessary more innovative ideas and initiatives. Deep renovations are expensive, even if they are cost-effective. They require considerable up-front capital that is normally beyond the support of any single financial instrument.
Moreover, new strategies to secure sufficient financing for deep renovations of the whole building stock are needed, which ideally bring together private and public investment streams. The future targets need to balance achievability and ambition: in fact, if they are too low, they reveal themselves meaningless, but on the other side, if they are too much high-flying and ambitious, it is likely that key-stakeholders will not engage in the entire innovation process.
Thence, policy makers and all the relevant stakeholders in the building sector should elaborate which policy framework would enable the necessary investments: and this would, not only create new investment opportunities for the private sector, but would also reduce the global burden on public budgets.

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Enhancing energy efficiency – Product related incentive schemes for the general public

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Abstract

Consumers are increasingly confronted with demands for CO_2 savings, increasing energy prices, power cuts and energy poverty. Especially low-income households do not have the financial means to buy energy efficient household appliances and they often lack the knowledge how to save energy in their daily life. However, from washing machines, refrigerators, lighting to outlet strips – in nearly every household there are appliances with relevant saving potentials.

By strengthening the awareness of private households through information and direct advice, consumers more likely adapt their use behaviour and thus reduce their energy consumption. Supporting the purchase of energy efficient appliances at the same time can also lead to a decrease of energy costs in private households.

Within the European project 'Common appliance policy – all for one, one for all – energy labels (ComeOn Labels)' [1], Öko-Institut has compiled an overview of a variety of informational tools and financial incentives with focus on replacement of household appliances to enhance the overall energy efficiency. The paper will highlight the overall benefits and results regarding energy savings and reduction of CO_2 emissions of the product related incentive schemes as well as discuss more detailed the different options and possible optimisations for the implementation of such programmes and initiatives.

Introduction - Underlying mechanisms of product related incentive schemes

White goods are generally being used for 10 to 20 years. Therefore, most private households still own a lot of old appliances with significantly lower energy efficiency than that of the best models on the market. And if they do purchase a new appliance, they often choose a product with a low upfront price (and higher follow-up costs); even if a highly efficient product would have the same or lower life cycle costs [2].

By promoting highly efficient appliances, i.e. devices of the best energy efficiency classes, a variety of ecological and economic savings can be achieved. According to [3] two general mechanisms can be distinguished that are briefly explained in the following.

Better replacement

Better replacement means that consumers choose a more energy efficient appliance than they would have chosen without the corresponding policy instrument. The fundamental decision to buy new equipment, however, has already been made. The environmental advantage arises from the lower power consumption of the "better" appliance. A class A++ refrigerator or freezer, for example, consumes about 45% less electricity than an A model of the same size and with the same technical and functional performance characteristics. An A+++ model consumes about 60% less [4]. Furthermore, highly energy efficient products can also be advantageous not only from an energy/environmental point of view. They can be also associated with lower operating costs, resulting in lower overall life cycle costs (i.e. the sum of all product-related costs affecting the consumer including the purchasing price).

Early replacement

Early replacement means the replacement of an (old) installed appliance although it is still working. Whether early replacement is environmentally beneficial or not, essentially depends on two factors: first, on the potential savings due to the reduced energy consumption of the new appliance, and secondly, on the environmental impact of the manufacturing and the disposal of the equipment, since the old equipment's useful life is not fully exploited.

In many product types, there is a large difference between the energy consumption of the average equipment in use and that of the most efficient new appliances available on the market. For example, an average refrigerator-freezer combination bought in 2000 in Germany, usually still quite functional today, consumes about 390 kWh of electricity per year. A class A++ appliance with the same storage capacity and technical and functional performance characteristics, however, only needs 180 kWh per year. Therefore, by replacing the old appliance with a highly efficient new one, around 210 kWh of electricity could be saved each year.

By contrast, the environmental impact (in terms of life cycle analysis (LCA) resulting from the production and disposal of household appliances is in general relatively small. Depending on the appliance and impact category, it accounts for 5-25% of the environmental impact throughout the equipment's entire life cycle (see Table 1).

Table 1: Global warming potential of selected household appliances in different life cycle phases

	Production	Use	Disposal	Source
Washing machines	25%	79%	--4%[1]	[5]
Tumble dryer (condenser dryer of energy efficiency class B	5,7%	94,1%	0,2%	[6]
Refrigerator/freezer combination (200 l + 90 l)	13%	89%	-2%	[7]

From an environmental point of view, therefore, early replacement often pays off. The "environmental payback period" denotes the time after which the environmental impact of the cumulative energy savings outweigh the additional environmental impact from the premature disposal of the old appliance. For the replacement of an average refrigerator-freezer combination manufactured in 2000 by a corresponding A++ appliance, this period is only about 2 years in terms of cumulative energy demand (CED) and global warming potential.

According to current information, valid for Germany, early replacement makes sense in particular for cold appliances, tumble dryers and circulators for central heating, as well as for electric and gas stoves. For other appliances like washing machines and dish washers an early replacement must be checked more carefully. There may be variations between EU Member States, though, mainly due to differences in climate conditions, consumer behaviour, the efficiency of the installed appliance stock and purchasing power.

However, even if environmentally beneficial, early replacement usually doesn't pay off in monetary terms – at least not in the sense that the purchase price of the new appliance will be completely compensated by the cost savings during its use phase. However, usually a noticeable reduction of electricity costs can be achieved. When replacing an average refrigerator/freezer combination built in 2000 with a corresponding A++ device, and assuming an average European electricity price of about 17 ct/kWh, about 35 EUR can be saved annually. It is difficult to compare the actual costs of "early" and "later" replacement though, since it is unknown for how long the old appliance would still have been serviceable in the "late" replacement case.

[1] The negative sign means that the disposal even has an environmentally beneficial effect, since the gains from recycling the material outweigh the negative impacts of the disposal and recycling process itself.

General choice of instruments to increase energy efficiency in private households

Overview

There is a variety of policy tools to increase energy efficiency in private households. According to [8] three basic categories of instruments can be distinguished:

1. Informational tools (such as labels, information campaigns)
2. Financial and fiscal incentives (such as direct subsidies, subsidized loans, indirect subsidies)
3. Regulatory tools (such as limit values or minimum requirements for new appliances)

Furthermore, there is the new category of cooperative tools such as voluntary agreements and network building.

In this paper, the focus is laid on the informational tools and financial incentives which will be explained into further detail.

Differences between instruments for better and early replacement

Not all tools and designs are equally suitable for all purposes. While measures to promote early replacements will always result in a better replacement, as they are also available to those consumers who just want to replace their old appliance anyway, the reverse is not true.

If early replacement is to be stimulated and the possible benefits that may be associated therewith are to be realized, certain criteria must be met:

- The measures must provide an appropriate financial incentive to consumers; otherwise there will be no reason to dispose of an old but still functioning appliance prematurely.
- The measures must be limited in terms of time or budget; otherwise consumers will just await the end of their appliance's technical life assuming that the incentive will still be in place by then. On the other hand, they must be long enough to support market transformation.
- The return and proper disposal of the old appliance must be part of the measure, otherwise it may continue to be operated as a spare device or supplied to the second-hand market.
- Also, the implementation of an effective system for the take-back of old appliances supports early replacement. In many EU countries, as a consequence of the WEEE directive, shops are obliged to accept any discarded appliances that customers bring back, independently of its brand or place of purchase.

The following sections list appropriate informational tools and financial incentives promoting particularly efficient household appliances. Labelling with the EU energy label as one example for an informational tool is taken for granted, thus only those going beyond the energy label are considered.

Informational instruments

In the domain of voluntary information measures, the credibility of the initiator or sponsor is relevant for their success. A high level of credibility increases the willingness of manufacturers to participate and the willingness of consumers to initially spend more money for highly efficient products or the early replacement of old appliances.

Communication of life cycle costs

This means consumers are given information on the financial savings they can achieve throughout the product life cycle by purchasing a highly efficient appliance. As we have seen, the argument is mainly valid for better replacement, and less so for early replacement. In contrast to a label only declaring energy efficiency, the communication of monetary information has the advantage that a general environmental benefit of a product is converted into an individual benefit for the consumer.

This is particularly advantageous when broader customer segments beyond the niche are to be addressed.

For example, Öko-Institut is participating in the European project 'YAECI - Yearly Appliance Energy Cost Indication' sponsored by the Intelligence Energy Europe (IEE) programme with the main objective to provide customers with information on the yearly running cost of products at the point of sale, in order to stimulate the uptake of affordable efficient products. [8] In the project running until March 2015, the following activities will be carried out in each participating country:

1. Development/ replication of a database with yearly running costs for the following products: cold appliances, washing machines, dishwashers, dryers, televisions;
2. Recruitment of retailers (in addition to the retailers who have already committed to participate at the start of the action);
3. Provision of information on yearly energy costs at the point of sale (shops) and on websites where the energy labelling class is shown of participating retailers;
4. Update of information on yearly running costs every 12 months;
5. Evaluation of the impact of the action.

Further on, there are several Internet platforms that present life cycle costs or at least operation costs/energy costs together with the presented products. One example, covering several European and non-European countries with specific websites is topten.info. In Germany the consumer information website EcoTopTen [9] presents the life cycle costs of energy efficient products in comparison to an average product of the same product category at its, see also next point.

Market overviews and product databases

Market overviews and product databases such as the German website www.ecotopten.de provided by Öko-Institut [10] or the European website www.topten.eu [11] facilitate the purchase process by providing potential purchasers with an overview of efficient products, their features and prices, and eventually their life cycle costs under average conditions. Hence, they are rather a tool for better replacement. They may be provided by different actors, such as national energy agencies, manufacturers' associations, NGOs or other independent bodies. An innovative element is the inclusion of a price competition, enabling potential customers to inform themselves not only about the average purchase price of the desired product but also about the cheapest supplier. With this method, the Danish site www.hvidevarepriser.dk achieved a major price reduction: Within three weeks, the recommended retail prices fell by 20% [12].

Additional voluntary labelling

In addition to the mandatory EU energy label, there are voluntary ecolabels both on EU level and in some national states (such as the German Blue Angel, the British label "Energy Saving Recommended" and the Danish Energy Saving Label.) The goal is to particularly reemphasize highly efficient products or products that, beyond the energy savings, meet further environmental and quality criteria. This measure can especially promote better replacement.

Voluntary labels can generally be quite cost-effective. A harmonization with other tools (e.g. GPP, incentive programs) and a regular update play a crucial role. So far, however, it could not yet be demonstrated that one of these voluntary schemes had a market transformation effect reaching beyond that of the EU energy label.

Information campaigns

Information campaigns must accompany many other instruments in order to draw consumers' attention to the existence of that instrument. Especially when aiming at early replacement, a comprehensive information campaign aimed at the general public is important in order to reach those consumers who are not currently facing a purchase decision and actively searching for information.

Information campaigns are relatively inexpensive. Their effectiveness, however, is difficult to assess. Just like voluntary labelling, they are generally more effective in combination with other tools (e.g. incentives for replacing an old appliance with an efficient new one).

Measuring energy consumption

The measurement of the energy consumption of appliances in private households is an appropriate measure to promote early replacement. Firstly, it may raise the consumer's awareness to an associated cost. Secondly, it can form an integral part of a broader programme. For example, in-house measurement may be used to determine the eligibility of a household / appliance to participate in a subsidy program.

Financial incentives

Direct incentives to consumers

The basic idea is to provide consumers who buy particularly efficient appliances (which are at the same time disposing of an old appliance) with a financial reward. This is one of the most popular instruments. Examples of national programmes abound, and there are even more examples of programmes set up by trade, manufacturers or energy companies.

If the measure is limited in terms of time or budget, rather early replacement will be stimulated. If it is planned on a long-term basis (i.e. over several years), better replacement is promoted more or less ad infinitum, thus bringing forward falling prices and a longer-term market transformation. Early replacement, however, is stimulated to a smaller extent, as there is no incentive to replace the old appliance unit as quickly as possible.

In the design of incentives, a number of conceptual questions need to be answered, impacting on the success of the measure:

- Target group (e.g. restriction to low-income households or households with particularly energy-intensive appliances?)
- Appliance groups to be promoted
- Criteria for incentive / requirements to be met by the appliance
- Amount of incentive (high enough to have visible effects; low enough to avoid free riders; differentiated according to appliance type and efficiency? differentiated for household income?)
- Duration of measure
- Organizational implementation of premium payment (e.g. by retailers or national agency?) and take-back of the obsolete appliances.

Incentives are often effective, but not always cost-efficient, which is due to free riders. To be cost-efficient, measures should focus on very innovative appliances currently still having high purchase prices, but a good potential for reducing them by economies of scale.

For example, in 2009 Öko-Institut was commissioned by the German Federal Ministry for Environment to develop an implementation concept for a product related subsidy scheme within the German Federal Climate Protection Initiative (NKI). [13] The project prepared concrete implementing measures and developed a master plan for the overall organization of the planned programme. Besides setting of ambitious criteria, the main responsibility of Öko-Institut was to coordinate and balance the different interests of the implementing organisations (Federal Ministry for Environment, the granting authority, the German Energy Agency, the Federation of German Consumer Organisations, the marketing agency) and the market actors (retailers, disposers, hundreds of thousands consumers) to ensure a smooth operation of the programme. Most of the challenges and arising questions could be clarified within the project, for example the advantages and disadvantages of different pay-out options, the proof of disposal, the requirements for products that shall be eligible, the amount of subsidies granted, additional electricity saving advisory services, possibilities for consumer information, as well as implementation of a database for products that shall be eligible. In the end, however, the German Federal Government decided against the implementation of the subsidy scheme.

A variant of the consumer subsidy is the “free giveaway”. For example, a popular measure in a number of countries has been the distribution of free energy saving light-bulbs. The effects are contested, however. First, free giveaways may destroy markets for these appliances. Secondly, free appliances are often not installed by consumers, limiting the effect. In the UK, this type if programme is therefore no more eligible as an energy saving measure under the Carbon Emissions Reduction Target (CERT) scheme.

In Germany, pilot projects (Stromsparcheck and Stromsparcheck Plus [14]) have successfully tested and applied the combination of energy checks and advice together with financial supporting the purchase of energy efficient appliances for low-income households. For example, they received free-of-charge appliances like energy saving lamps, water-saving flow regulators and outlet strips. By these direct installations, CO_2 and energy cost savings could be realized. Further, the project resulted in social benefits as long-term unemployed persons were trained to “energy savings assistants” implementing the energy checks in the households. [15]

A further variant would be to just offer an incentive for disposal of the old appliance, without subsidizing the new one. This could take the form of a bonus for having an old appliance removed.

Fiscal incentives for consumers

Tax incentives have been extremely successful for major household appliances in Italy. But in other countries, they are rarely applied for household appliances. This is probably due to the comparably low purchase price of these devices, and, as a result, of the high administrative costs. Also, the lack of an immediate connection between appliance acquisition and financial benefit reduces the psychological effect. Tax benefits therefore are primarily applied in the building sector, relating to equipment such as boilers, water heaters or air-conditioning systems. They can take the form of tax credits, deductions from income tax or enhanced capital allowances and may be financed by an energy tax which is "returned" to consumers in the form of appropriate incentives. Depending on operational features (limited in time or not), tax incentives can be appropriate means for both better replacement and early replacement.

Another variant is to reduce the VAT rate and thus the selling price for highly efficient appliances. However, due to EU VAT rules, reduced VAT rates may only apply to building-related measures, such as water heaters [16]. Furthermore, appliance manufacturers are sceptical of this measure, as the subsidy is not transparent to the consumer. Seeing only the final price, consumers might believe that highly efficient appliances are cheaper to produce than ordinary equipment, and their willingness to pay will (further) decline. All in all, these reasons suggest that this tool is not recommendable.

Tax incentives can be both effective and cost-efficient but there are also other cases where they showed little effect and high windfall profits. A windfall occurs when individuals are funded by the State for an action that they would have made even without State support. The higher the windfall, the lower the effectiveness of the measure. For an example of high windfall profits of 70-80% from modernising insulation of buildings see [17].

Therefore, design details are crucial. Among the criteria of success are: reliability, good timing, stakeholder participation and accompanying information measures, regular updates, appropriate level of requirements, selection of appropriate appliances (in most countries, products whose purchase price proves to be a major hurdle).

Indirect subsidies

In the case of indirect subsidies, as practised in the "Eco-point" system in Japan or the Korean "Carbon Cashbag", consumers obtain credit "points" instead of money upon the purchase of a highly efficient product [1]. Then, these points can be traded for certain products or services (e.g. for discounts in public transport, for other environmentally friendly products, cultural events, etc.). Another variant is that consumers can acquire vouchers or bonus points when they buy other products, or as a bonus on their salary, which can then be used to purchase highly efficient appliances.

The advantage of such indirect subsidies as compared to the disbursement of money is that the type of products or services that can be bought to receive the subsidies can be influenced. This can at least reduce direct rebound effects (when subsidies / refunds are used to purchase flights or other products with high CO_2 intensity).

Bonus/malus programmes

Bonus / malus programmes aim at adjusting the price of energy-using products according to their efficiency. When buying a highly efficient appliance, an allowance (bonus) is granted to the consumer, while he or she must pay an additional amount (malus) on purchase of a particularly inefficient product. When buying an average appliance, neither a bonus nor a malus does accrue.

The advantage of this tool is that it can be set so that it will either generate net revenues, that it will be revenue-neutral, or that subsidies will be needed. In designing the instrument, it is important that the threshold value between bonus and malus (i.e. the average efficiency) will be regularly adjusted to the market development. Due to the malus element, this is a tool to promote better rather than early replacement, as consumers buying less efficient appliances will actually be penalized.

So far, there is only one example, namely for automobiles in France. Here, the tool was linked to the CO_2 emissions, which has proven to be very effective. The market share of cars of emission class B has risen from 20 to 33% while the share of class G cars has been halved. An extension of the scheme to other products is being discussed.

Micro-credit models

Micro-credit models aim at eliminating the hurdle of high upfront costs by granting advantageous loans for the total purchase price or a part thereof. They are currently mainly used in the building sector and less for household appliances. The advantage may either reside in subsidized loans (low / no interest rates) and/or in a specific repayment mode, i.e. the loan will be repaid through the savings resulting from the lower energy consumption during the use phase. The latter is also known as "contracting". Credits/loans may be offered by different actors, such as governments, independent agencies, energy providers or third parties (e.g. ESCOs, Energy Service Companies).

- Government loans are generally only relevant in the building sector. Due to high transaction cost, they are not yet granted for household appliances.
- Due to various barriers, loans by third parties are only granted to a small extent, so far. Government subsidies could, however, stimulate the granting of loans by third parties.
- When loans are granted by energy providers, the latter installs energy-efficient appliances, which are paid with the monthly energy bill. The savings in energy consumption costs at least partly offset the costs for the installation of the device. There are both the credit and the rate variant: While the credit is tied directly to the customer, who has to pay it back even if he moves house, the rate is bound to the consumption meter and thus to the real estate. The rate option has the advantage that even tenants can participate without taking a greater risk.

This measure is mainly suitable for better replacement. It can be used for early replacement, too, if it would be temporary limited so as to provide an incentive to immediately replace the old appliance, and connected with a return of the obsolete appliance.

One problem that is encountered with this tool is that it often fails to reach the neediest households as well as tenant households. Further issues are high costs associated with the programme, the low participation rate, and the difficulty to make realistic estimates of the savings in advance.

Financial incentives for producers (upstream incentives) or retailers and installers (midstream incentives)

Producers may receive financial incentives to produce and sell more highly efficient appliances or to reduce their prices. Lower consumer prices improve the conditions both for better and early replacement. Such incentives may, for example, take the form of tax credits per produced unit or of a grant if certain criteria are met. Such incentives are particularly effective when the market is dominated by a few large producers that are present in all countries.

Furthermore, as a tool for better replacement, sales personnel or installers receive (financial) incentives to sell particularly efficient appliances. Hence, they will preferentially offer these appliances highlighting them in their sales discussions.

As compared to incentives offered directly to consumers, benefits of upstream or mid-stream incentives may be:

- lower transaction costs, because the number of manufacturers or retail companies is significantly lower than the number of consumers. Also, instead of many different criteria influencing the private consumer’s buying decision, profit is basically the only decision criterion in companies;
- lower incentive needed, as trade margins and taxes are avoided;
- lower total costs for the state, as losses in the electricity tax and costs of the tax relief are compensated by increased VAT revenues and increased corporate in-come taxes.

On the other hand, these instruments contribute less to consumer awareness and sensitization. Also, compared to end user rebates, it is mostly retailers and manufacturers who profit financially. Distributional effects therefore have to be considered.

Outlook: Integrated strategies

Integrated strategies combine several of these tools. In Denmark, for example, there have been three campaigns aimed at promoting highly efficient refrigerating appliances, combining a subsidy with an aggressive marketing campaign and a website launched to enable consumers to search for products and to compare prices. Another Danish campaign, targeting highly efficient circulators, linked voluntary agreements with manufacturers, retailers and installers with a voluntary labelling and a proactive marketing. A programme to replace old refrigerators in Oregon combined information measures, measurement of the household’s energy consumption, personal contact, financial incentives and comprehensive services for households.

In addressing different phases of the market launch process as well as different barriers, sophisticated combinations have proven to be more powerful than individual measures. Therefore it is suggested to consider an adequate bundle of single measures, addressing e.g. manufacturers, retailers and consumers and using different ways of addressing and involving people (e.g. personal contact, websites, interactive communities) when developing a new incentive scheme.

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An Investigation of China's Subsidy Program for Energy-saving Products

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Abstract

Subsidy is used in many countries as an important instrument to promote energy-saving products. China started subsidizing energy-saving products, including light bulbs and automobiles, in 2009. The subsidized product groups quickly expanded to major home appliances such as air conditioners, flat-panel TVs, refrigerators, washing machines and water heaters. The latest subsidies for purchasing the five types of energy-saving products reached 26.5 billion RMB since June 2012. It is expected that even larger financial budgets from the Chinese government will be allocated to support the wide deployment of high energy efficient products according to the national 12th Five-Year-Plan, which adopted the "energy conservation and emission reduction" as the national long-term development strategy.

In this paper, the policy framework of China's Subsidy Program for Energy-saving Products is reviewed. The recent subsidy schemes for air conditioners, flat-panel TVs, refrigerators, washing machines and water heaters are introduced. Based on retail market data, an investigation of the market status for the five types of products is conducted. The subsidy schemes are analyzed in terms of products' properties such as type, size, energy efficiency tiers, price, functional capacities etc. This paper concludes with suggested options to improve the subsidy program.

Introduction

In order to mitigate climate change and sustain human development, changing the way in which we use energy is more economically efficient than simply increasing the energy supplies. Energy efficiency was addressed by the Mckinsey & Company [1] as a cost-effective tool to fulfill this goal. In the last three decades, much effort has been made on promoting energy efficient appliances and equipment including technologies, regulation measures (e.g. MEPS - Minimum Energy Performance Standards - and mandatory labeling schemes such as Energy Label in China and Europe), financial incentives (e.g. tax, electricity price etc.), voluntary actions (e.g. endorsement labels such as "Energy Star" in USA) and more. Among financial incentives, subsidies are widely used in various ways to increase market penetration of energy-saving products in developed economies such as Europe [2] and USA [3].

China is now the world's largest carbon emitter [4]. With China's fast urbanization and increasing deployment of electrical appliances, the share of residential electricity consumption over total electricity consumption went up from 3.5% in 1980 to 12.5%[1] in 2012. Given the continuing trend in middle class growth, the residential electricity consumption in China will remain high in the coming years. Additionally, China has become a dominant player globally, which produces the majority of the world's home appliances. A report[2] showed that the nation's production capacity of color televisions accounted for 80% of the world's total. The production capacity of air-conditioners, refrigerators and washing machines also accounted for 70%, 50% and 40%, respectively. In August 2012, the State Council issued the 12th Five-Year-Plan on Energy Conservation and Emission Reduction in which China announced a goal of 16% cuts in energy consumption per unit of GDP by 2015 along with carbon dioxide emissions set to be cut by 17% from 2010 levels. This strong political commitment has led to a series of policy initiatives in which the so-called "Jienenghuimin" project [5] (a project to promote energy-efficient products for the benefit of the people) is a key subsidy program during this

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[1] Data published by China National Energy Administration. http://www.gov.cn/gzdt/2013-01/14/content_2311167.htm (in Chinese and read in January 2013)

[2] A report published by the China Economic Weekly, using data from the China Household Electrical Appliances Association, 2012.

five-year period to stimulate demand for products and drive market transformation towards higher energy efficiency.

China had subsidized efficient lighting products since 2008. Based on a series of important decisions (Guofa [2006] No.28 and Guofa [2008] No.23, see Table 1) made by the State Council, the "Jienenghuimin" project was initiated in June 2009. Together with the lighting products, air conditioners and cars were included into this program. The subsidies are given to manufactures by the central government. The participating manufactures must register to the program according to implementing rules for a specific product category. Additional cost between an energy-efficient model and an inefficient one is determined and taken as the subsidized amount to remove the purchase barrier for expensive efficient products. In general, the manufactures/retailers pay customers cash first (except cars) and they can only get the subsidy back from the government when they fulfill mandatory requirements such as a certain amount of registered models were sold, all procedures are proper and they pass the monitoring inspection etc. The energy efficient appliances are defined in national energy efficiency standards by "evaluating values of energy conservation" which is the minimum requirement for energy-efficient products certification (a voluntary endorsement label). The evaluating values of energy conservation also determine tier 2 products in the mandatory China Energy Label. Under this context, energy efficient appliances are known as those products which have the energy-efficient products certification, and those which are ranked tier 2 and tier 1 in China Energy Label. By the end of the 2010, 16 billion RMB were spent and 34 million efficient air conditioners, 1 million efficient cars and 360 million efficient lighting bulbs were sold and subsidized. The market share of energy efficient products has been highly increased, e.g. the market share of energy-efficient air conditioners increased from 5% to 70%. It was estimated that through this round of subsidies, 120 billion RMB of domestic demand was stimulated, 22.5 billion kWh of electricity was saved annually and 14 million tons of CO_2 emissions were reduced[3].

Table 1: Policy documents for the subsidy project "Jienenghuimin".

Content	Document No.	Publishing Time
State Council Decisions on Energy Conservation	Guofa [2006] No.28	Aug 6, 2006
State Council Notice on Energy Conservation	Guofa [2008] No.23	Aug 1, 2008
Implementing rules for lighting products	Caijian [2007] No.1027	Dec 28, 2007
Official kick-off of the project and the subsidy management framework	Caijian [2009] No.213	May 18, 2009
Implementing rules for air conditioners	Caijian [2009] No.214	May 18, 2009
Implementing rules for air conditioners (adjusted)	Caijian [2010] No.119	Apr 30, 2010
Implementing rules for cars (with displacement lower than 1.6L)	Caijian [2010] No.219	May 26, 2010
Implementing rules for electric motors	Caijian [2010] No.232	May 31, 2010
Implementing rules for flat-panel TVs	Caijian [2012] No.259	May 25, 2012
Implementing rules for air conditioners	Caijian [2012] No.260	May 25, 2012
Implementing rules for household refrigerators	Caijian [2012] No. 276	Jun 4, 2012
Implementing rules for washing machines	Caijian [2012] No. 277	Jun 4, 2012
Implementing rules for household water heaters	Caijian [2012] No. 278	Jun 4, 2012

Note: Analysis is based on the highlighted policy documents in this paper.

From June 2012, a new round subsidy program with a larger scale of budget (26.5 billion RMB) has started and it covers five major household appliances including flat-panel TVs, air conditioners, household refrigerators, washing machines and household water heaters. Under such context, questions are raised, for example, how will this new policy shift the market? Can the regulation measures such as MEPS and labeling schemes effectively support this policy? How can you make this policy an opportunity to save more energy? To answer these questions, we reviewed this new

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[3] Data published by National Development and Reform Commission. http://www.sdpc.gov.cn/xwfb/t20111009_437354.htm (in Chinese and read in February 2013)

policy and investigated the Chinese retail market for these five kinds of products. Based on our analysis, we introduced our findings and provided recommendations to improve the effectiveness of this policy.

China's MEPS, Labeling and Certification System

As the technical basis of implementing financial incentives for energy-saving products such as government procurement and subsidy programs, China has built an energy efficiency standards, labeling and certification system (see Figure 1).

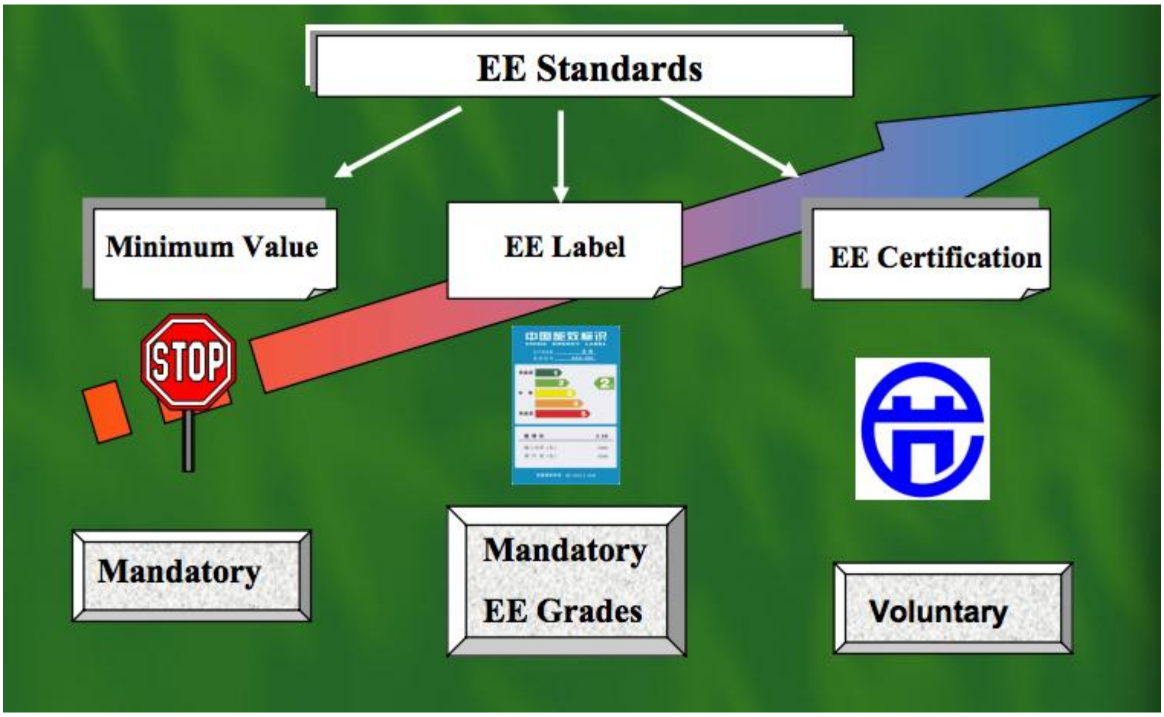


Figure 1: China's Energy Efficiency Standards, Labeling and Certification System (source: Cheng Jianhong, China National Institute of Standardization (CNIS), March 2009).

Figure 1 helps explain that the Minimum Energy Performance Standards (MEPS) eliminate inefficient products from the market. Comparative labeling and grading schemes (the mandatory China Energy Label) create market transparency that is particularly helpful for consumers to select energy efficient products, while the voluntary endorsement certifications (with energy efficient products labels) encourage manufactures to produce more high energy efficient products and to keep innovating energy-saving technologies.

From 1989 to 2012, China has established 48 MEPS covering household appliances, lighting equipment, commercial equipment, industrial equipment, vehicles and office equipment. Adapted from the EU energy label, China launched the mandatory "China Energy Label" [6] in 2005. As a comparable information label, three or five tiers are defined in the product MEPS. Tier 1 has the highest energy efficiency; tier 2 specifies the evaluating values of energy conservation for the product, which are the minimum requirements for energy-saving product certification; and the last grade (3 or 5) sets the minimum allowable values of energy efficiency, which are the threshold of market access. The principles of setting standards and grading the products are based on market statistics. To ensure a reachable value and enough product availability, top 15%-20% products in the market are identified as energy efficient products (tier 2 and tier 1). 10%-15% are to be eliminated as inefficient products from the market, and the rest in the middle are pushed to reach a higher level of energy efficiency. By the end of 2012, China Energy Label had covered 27 product categories. The MEPS and energy label information for the five subsidized products can be seen in Table 2.

Table 2: China's MEPS and energy label for the target five subsidized product categories.

Product	MEPS Reference	Standard Implementation Date	China Energy Label Implementation Date	Energy Efficiency Tiers
Flat-panel TVs	GB 24850-2010	2010-12-1	2011-3-1	3
Variable speed air conditioners	GB 21455-2008	2008-9-1	2009-3-1	5
Fixed speed air conditioners	GB 12021.3-2010	2010-6-1	2005-3-1	3
Refrigerators	GB 12021.2-2008	2009-5-1	2005-3-1	5
Washing Machines	GB 12021.4-2004	2005-5-1	2007-3-1	5
Gas water heaters	GB 20665-2006	2007-7-1	2008-6-1	3
Solar water heaters	GB 26969-2011	2012-8-1	2012-9-1	3

Based on these MEPS and the energy label implementing rules, the subsidy schemes were made and implemented for each product category. Since tier 2 specifies the minimum requirement for energy-saving product certification, the subsidies usually went to the models that fulfill energy efficiency requirements for tier 1 and tier 2. However, technologies innovate very quickly and the market transforms all the time, so the regulation measures, including MEPS, labeling and subsidy schemes, shall follow the market and change themselves accordingly.

We investigated market status of the target subsidized energy efficient products. The model-based distribution of energy efficiency tiers of each product is illustrated in Figure 2.

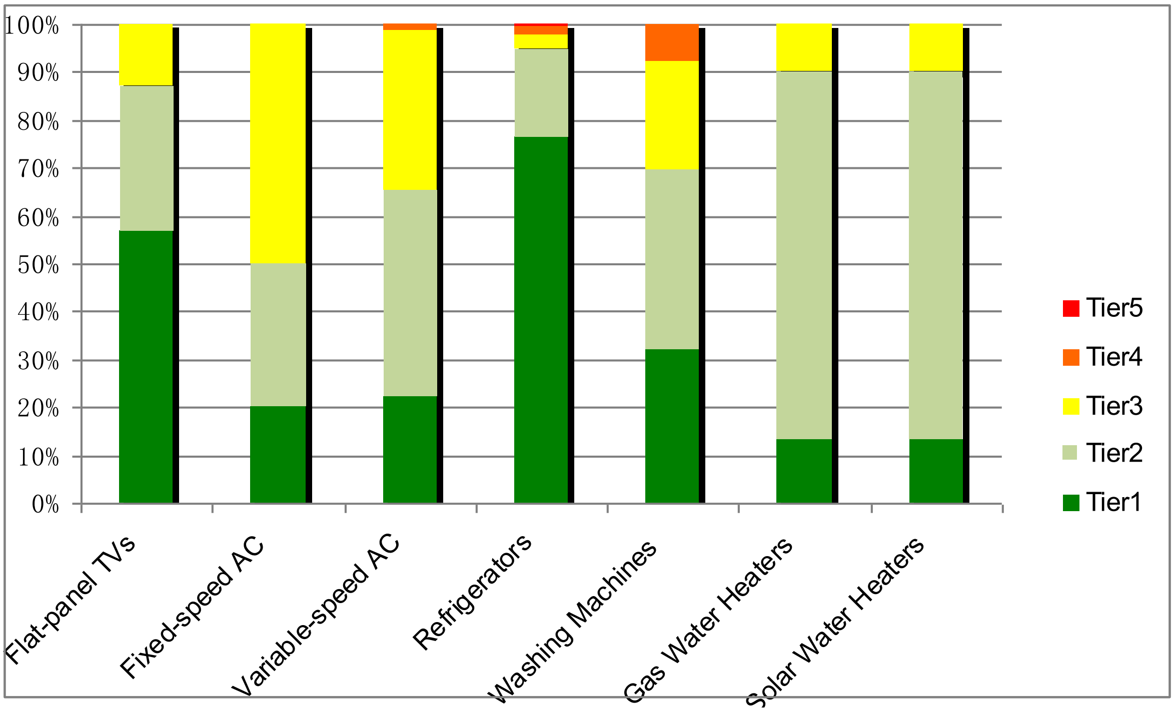


Figure 2: Distribution of energy efficiency tiers for target subsidized energy using products on Chinese retailer market by May 2012 (model based without sales data).

The share of tier 1 products for refrigerators, flat-panel TVs and washing machines are 76%, 57% and 32% respectively, which is too high to determine the actual energy efficient products. About 77% models of gas water heaters and solar water heaters are tier 2 products, so this is too hard to tell they are actual energy-saving products although all of them may have the energy efficient products certification. The share of tier 1 together with tier 2 products for the five products is all more than half of the models, so that subsidies shall not simply go to tier 1 and tier 2 products, but be used for those actual top efficient products.

Subsidy Schemes & Analysis

Our analysis was conducted on an available product model (*not sales*) basis. Several data sources including retailers, independent market research companies and labeling programs were integrated into one database for the analysis. It examines product type, size, energy efficiency tiers, energy consumption and efficiency index, price, functional capacity etc, and the correlation between these factors. In the following we review the policy, present our main findings and introduce what our analysis means to the subsidy schemes and how the policy can systematically be improved. The detailed subsidy schemes and analysis for each product are introduced as follows.

Flat-panel TVs[4]

MEPS for flat-panel TVs (GB 24850-2010) regulate two basic types of flat panel technologies that dominate the television market, Plasma Display Panels (PDPs) and Liquid Crystal Displays (LCDs). LCD televisions break down further into two types differentiated by the backlighting source, either Cold Cathode Fluorescent Lamps (CCFLs) or Light Emitting Diodes (LEDs). During 2008 and 2009, backlighting technologies have been rapidly innovated and in particular, the high efficiency LED has replaced traditional CCFL and become the dominant backlight in China's market. In June 2012, we analyzed 2337 models of which 66% were LED, 28% were CCFL and only 6% were PDP. Because of this fast technology upgrading, the market shifts to higher efficiency rapidly and 80.9% (see Figure 3) of LCD TVs based on LED backlight technology can reach the energy efficiency level Tier 1.

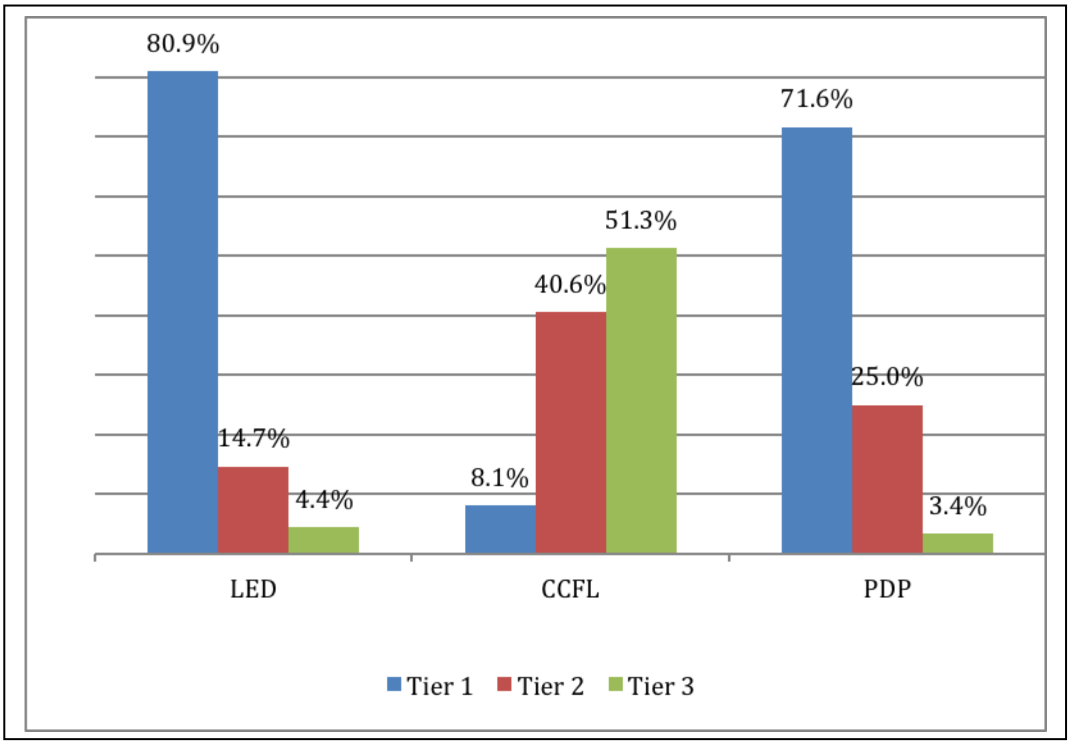


Figure 3: Distribution of televisions on the market in July 2012 across the 2010 energy efficiency standard tiers (note derivation of EEI's not comparable between LED/CCFL televisions and PDP televisions)

[4] http://www.sdpc.gov.cn/zcfb/zcfbqt/2012qt/t20120529_482367.htm

The latest subsidy program (see Table 3) only supports flat-panel TVs with EEIs higher than the current Tier 1 (GB 24850-2010) requirement. This illustrates policy makers are aware that the current Tier 1 requirements for LCD and PDP televisions are not sufficiently high to reflect the current levels of higher efficiency televisions. Further, the subsidy thresholds set suggest EEIs of 1.7 for LCD and 1.4 for PDP represent energy efficient products, and EEIs of 1.9 for LCD and 1.7 for PDP represent highly energy efficient products.

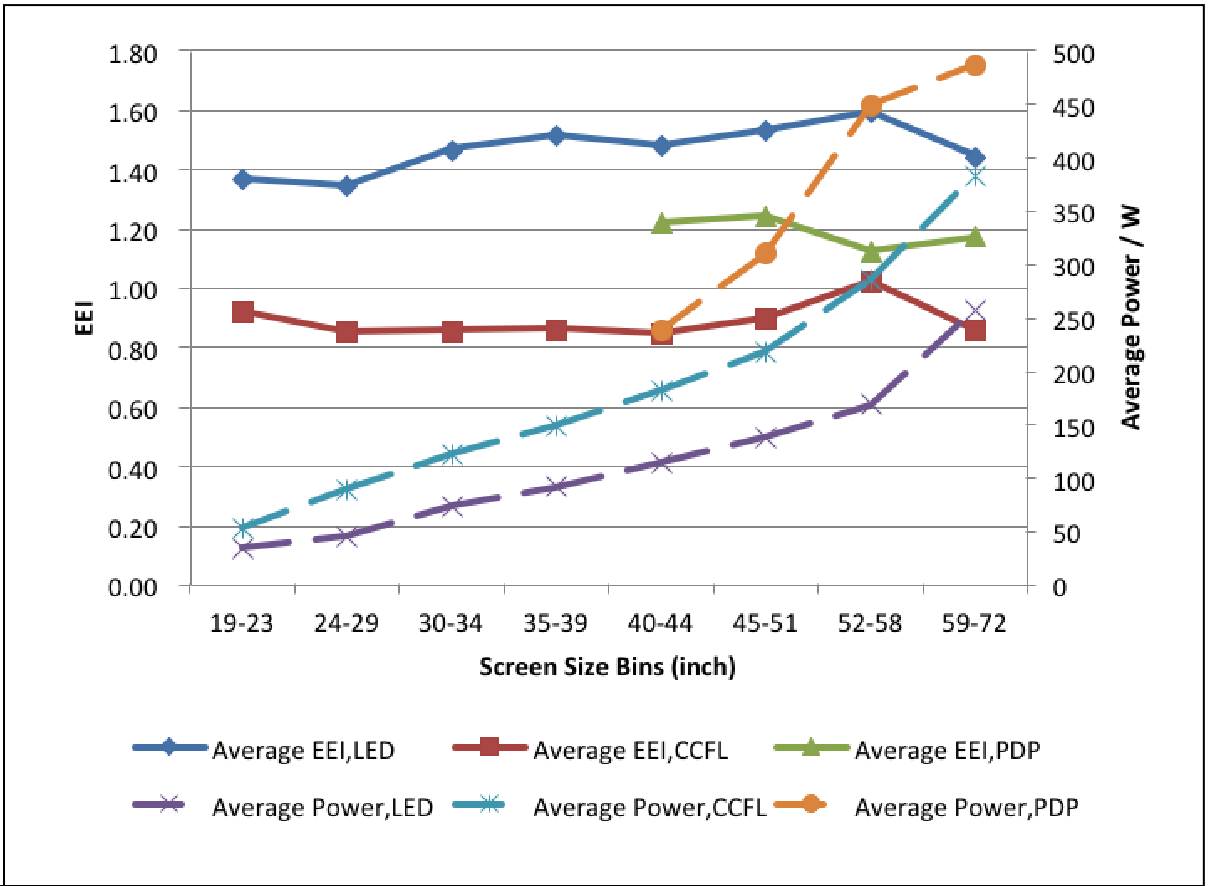
Table 3: Subsidy scheme for flat-panel TVs of varying efficiency and screen size (Energy Efficiency Index values calculated using GB 24850-2010).

Screen Size (inches)	**Liquid Crystal Display - LCD (RMB/Unit)**		**Plasma Display Panel - PDP (RMB/Unit)**	
	EEI>=1.7	**EEI>=1.9**	**EEI>=1.4**	**EEI>=1.7**
19-32	100	150	-	-
32-42	250	300	250	250
42 and above	350	400	350	350

However, in the coming MEPS revision draft, the proposed minimum energy performance requirement (MEPR) for LCD and PDP are 1.7 and 1.4, respectively. This means these values will be the requirement as an entry level. In this case, it reflects that the requirements for this subsidy policy are not stringent enough as declared to be only for efficient products, and most of the televisions on the market could benefit from it.

Secondly, there is only EEI and passive standby power information on the energy label so ordinary consumers are highly unlikely to understand the meaning of EEI. They don’t have any idea how much energy the TV consumes per day for a certain time of use. This gives the consumer no indication that that a PDP television is actually consuming significantly more energy than an equivalent LCD model, and thus removes the consumer’s ability to chose the fundamentally more efficient LCD television with the associated lower energy consumption. The reason is that the EEI thresholds defined in the MEPS for LCD and PDP televisions are not directly comparable. A compensation coefficient “$EFF_{PDP,ref}$” is defined to calculate EEIs for PDP televisions on an equivalent basis to LCD televisions. It means that both technologies can “fair play”, however without adoption of the “technology neutrality” approach as well as the information transparency for energy consumption, the energy label loses its nature of “saving energy by information”. We believe that the PDP TVs shall not be subsidized anymore and subsides shall only go to energy-saving technologies such as LED.

We also found that there is no energy consumption cap in the subsidy schemes, i.e. from the point of view of saving energy, subsidy program should exclude extremely big size TVs such as TVs over 60 inches because, based on the actual living condition in China, TVs bigger than 60 inches could be regarded as luxury products with very high energy efficiency but TVs consume more energy when they are bigger (See Figure 4) and should not be encouraged for purchase if a relatively smaller size product could meet the needs. TVs with bigger size get more subsidies. This will encourage



consumers to buy big sized TVs which consume more energy. Of course, the subsidy program has also goals to stimulate the domestic market and boom the economy. But without having a cap to control the total energy consumption, the "Jevons paradox" might happen.

Figure 4: Relationship between the energy efficiency index, power and screen size of televisions*

*Due to limited data availability, the data of power is not complete for all models. Power data was available for 1,547 models consisting of 925 LED models, 520 CCFL models and 102 PDP models.

Air conditioners

Fixed speed air conditioners were within the first batch of subsidized products in 2009. The subsidy scheme is listed in Table 4. Both the fixed and variable speed air conditioners are included in the latest subsidy program from June 2012 to May 2013. The subsidy scheme is shown in Table 5.

Table 4: Subsidy scheme for fixed-speed air conditioners (2009 ~ 2011).

Cooling	2009.6 ~ 2010.5[5] (RMB/Unit)	2010.6~2011.5[6] (RMB/Unit)

5 http://www.sdpc.gov.cn/zcfb/zcfbqt/2009qt/t20090525_281606.htm

Capacity (W)	Tier 1	Tier 2	Tier 1	Tier 2
CC≤2800	500	300	200	150
2800<CC≤4500	550	350	200	150
4500<CC≤7100	650	450	250	200
CC>7100	850	650	/	/

Table 5: Subsidy scheme for fixed-speed and variable-speed air conditioners (2012).

Cooling Capacity (W)	Fixed speed air conditioner (RMB/Unit)		Variable speed air conditioner (RMB/Unit)	
	Tier 1	Tier 2	Tier 1	Tier 2
CC≤4500	240	180	300	240
4500<CC≤7100	280	200	350	280
CC>7100	330	250	400	330

It was reported [7] that during the first subsidy period (2009-2010), the subsidized price (i.e. original price minus the subsidy) of an efficient air conditioner, with power consumption of around 1.5HP (horse power), was cheaper by 2000 RMB for tier 1 products, and by 1500 RMB for tier 2 products than its original price. It is clear that the latest subsidy scheme for air conditioners is not as generous as in the first phase. We found that taking the subsidy into consideration, it cannot sufficiently close or reduce the price gap between tier 1, tier 2 and tier 3 products (see Figure 5).

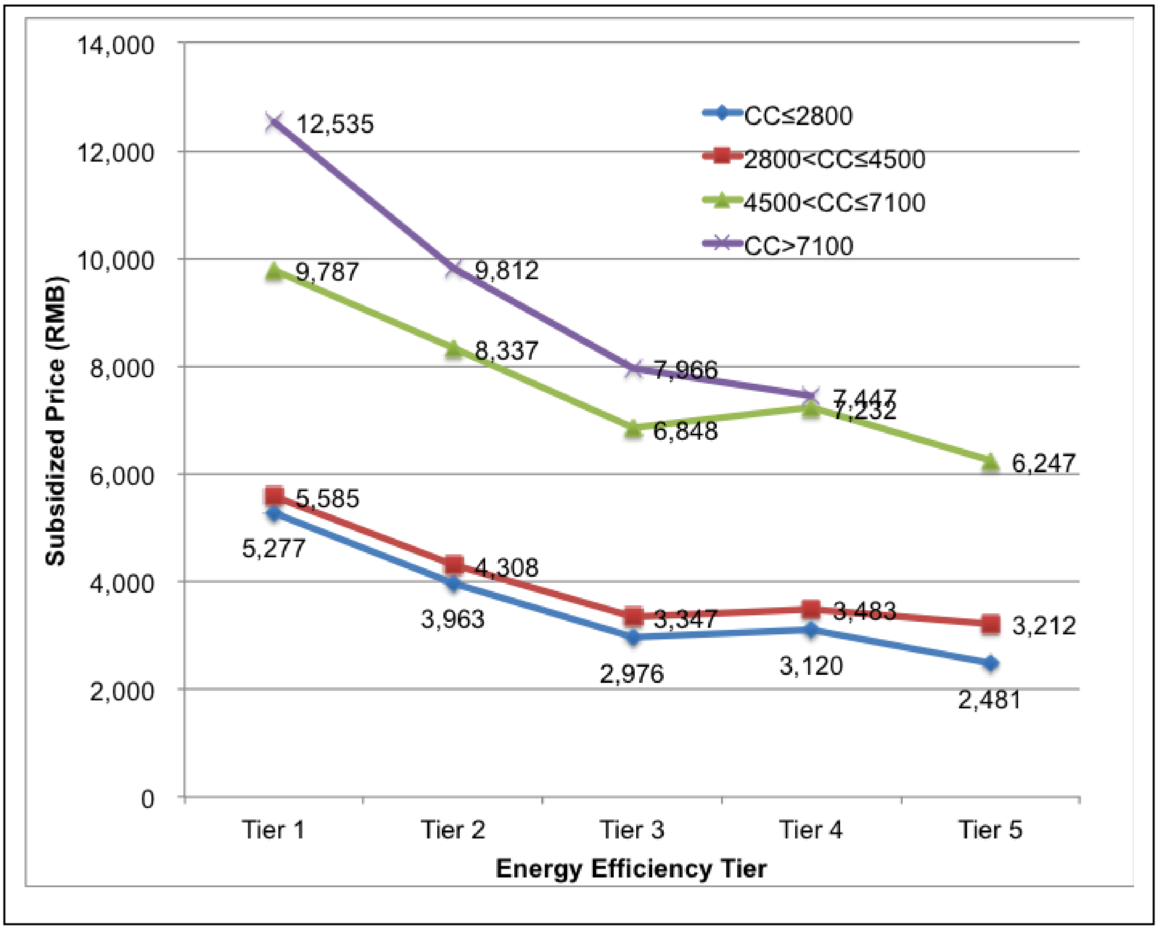


Figure 5: Subsidized average price of each efficiency tier in four cooling capacity groups

The price gaps and the increasing rate are shown in the Table 6.

[6] http://www.sdpc.gov.cn/zcfb/zcfbqt/2010qt/t20100511_346219.htm

Table 6: Price gaps and increasing rate among the tiers.

Tier	Price Gap (%)				Price increasing rate (%)			
	CC≤2800	**2800<CC≤ 4500**	**4500<CC ≤7100**	**CC>7100**	**CC≤2800**	**2800<CC ≤4500**	**4500<CC ≤7100**	**CC>7100**
1~ 2	1,399	1,345	1,519	4,287	33	30	18	37
1 ~ 3	2,584	2,550	3,289	7,814	86	76	48	98
1 ~ 4	2,457	2,402	2,905	8,332	79	69	40	112
1 ~ 5	3,097	2,673	3,890	6,880	125	83	62	77
2 ~ 3	1,184	1,205	1,769	3,526	40	36	26	44
2 ~ 4	1,058	1,057	1,385	4,045	34	30	19	54
3 ~ 5	1,697	1,328	2,371	2,593	68	41	38	29

The price difference between high efficiency products and lower efficiency products is so great that the higher tier models are at least 20% more expensive than those in lower tiers. Potentially, the price gap is large enough for the consumers to switch to the low efficiency products when they make their purchasing decision. It is speculated that the actual manufacturing costs of the high efficiency products are not as high as reflected by the price differences, as shown above. It is possible that the manufacturers and retailers are using the high efficiency tiers as a marketing tool to boost the retail price.

Refrigerators[7]

The implementing rules for subsidizing refrigerators took effect on June 4, 2012 with subsidies for energy-efficient refrigerators ranging from 70 RMB per unit to a maximum of 400 RMB per unit, depending on efficiency tiers and refrigerator type. The detailed subsidy scheme is shown in Table 7.

Table 7: Subsidy scheme for household refrigerators (2012).

Refrigerator type		**Subsidy Amount (RMB/Unit)**	**Energy Efficiency Requirement**
Freezer, Fridge/Freezer	Total Storage Volume (TSV) ≤120L	70	Energy Efficiency Index (η) ≤ 50% Tier 1
	120L< TAV ≤ 300L	130	
	TSV > 300L	180	
Fridge Freezer, frost-free fridge freezer	TSV ≤ 240L	260	η ≤ 32%
	240L < TSV ≤ 300L	330	
	TSV > 300L	400	η < 40% Tier 1

China Energy Label for refrigerators does have energy consumption information (kWh/24h), but there is no Energy Consumption Cap included in this subsidy scheme. It is still designed according to the EEI that is calculated as the ratio of the measured energy consumption of the unit during the test to the baseline value (maximum allowable value was proportionally set to the baseline value) of energy consumption. Since 90% of the available models in the retailer market are fridge freezers, we investigated 1143 of them in terms of EEI. 73.8% are tier 1 products and 248 models' EEI are lower than 32%. This indicates the subsidy scheme could be more stringent and the MEPS needs to be revised as well.

By the end of November 2012, 4197 refrigerator models had been registered and will be covered by the national subsidy programs. While it is possible that the subsidy has fulfilled its primary focus of stimulating demand for products, it appears the secondary goal of driving higher product efficiency

[7] http://www.sdpc.gov.cn/zcfb/zcfbqt/2012qt/t20120608_484887.htm

has not been fulfilled. It appears the subsidy program for refrigerators was designed based on outdated product information and thus a very high proportion of refrigerators were eligible for the subsidy rather than restricted to the higher efficiency products.

Currently 14.3% of the 4197 models that have been registered to receive a subsidy have a storage volume over 300L and will be given 400RMB per unit, of those, 9.1% have a volume over 350L. While sales figures for these models are unknown, the data from GOME[8] suggests that larger units are taking an increasing proportion of the market. If such big amounts of money can be used to subsidize the small and middle-sized refrigerators, the concept of both sufficiency and efficiency can be covered in this program.

Since the manufactures and retailers get more profit from the high-end market of refrigerators and the people who buy these expensive products are less likely to be sensitive to price, the impact of the subsidy is likely to be marginal even when at the maximum subsidy level of 400RMB. Figure 6 illustrates how the bigger the subsidized refrigerator is, the lesser percentage the subsidies account for from the average prices for the initial purchase. China's new subsidies average less than 10% of the appliance cost. Therefore, it is potentially helpful to stop subsidizing money-and-energy-consuming products and instead, add this budget to increase subsidies to attract the customers to buy ultra-energy-efficient refrigerators with the best energy-saving technologies.

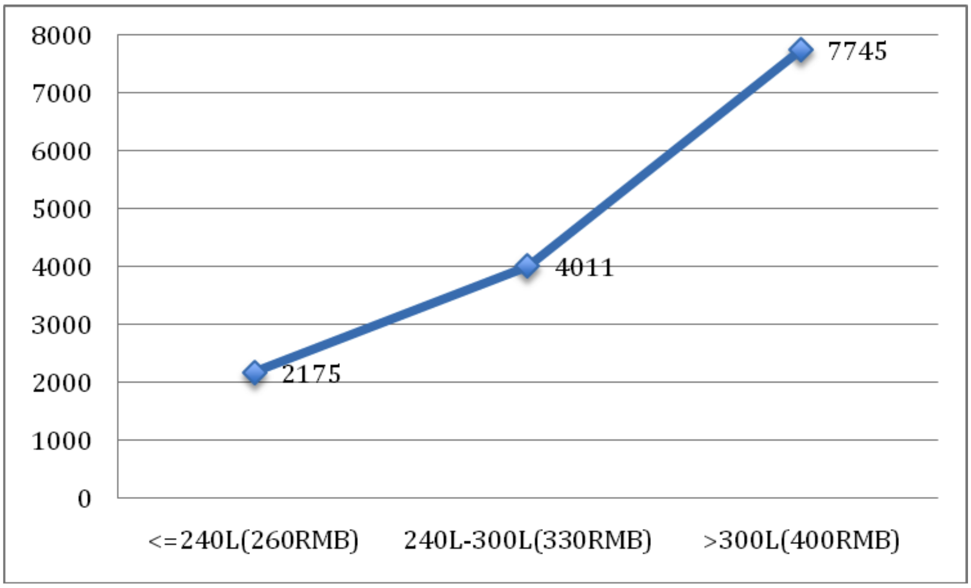


Figure 6: Average prices (RMB) for refrigerators with different subsidized volume groups.

Furthermore, it is found that some manufactures registered their refrigerator models for the subsidy with exactly the minimum value of the required energy efficiency index[9]. This raises risk for the monitors of the policy. To effectively examine and verify such kind of values, it is useful to define the tolerances that the tested parameters shall be subject to, namely each measured value shall be within the allowed tolerance from the value as required or declared.

Washing machines[10]

There are two main technologies of washing machine on the Chinese market: drum (front load) and impeller (top load). GB 12021.4-2004 regulates these two technologies with the same indicators

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[8] It is estimated by GOME, one of the biggest electrical appliances retailers in China, that the market share of three-door and side-by-side door refrigerators (both of which typically use more energy than their two door top vertical equivalent units) will increase from 50% to 65% in 2012.

[9] http://www.sdpc.gov.cn/zcfb/zcfbgg/2012gg/W020120914638886942311.xls (read in October 2012)

[10] http://www.sdpc.gov.cn/zcfb/zcfbqt/2012qt/t20120608_484897.htm

including energy consumption (kWh/cycle/kg), water consumption (L/cycle/kg) and washing ability. Both types of product are included in this subsidy program and the scheme is shown in Table 8.

Table 8: Subsidy scheme for washing machines (2012).

Product type	EET and Energy efficiency requirements	Subsidy amount (RMB/Unit)
Full-automatic impeller	Washing capacity≤3.5 kg, tier 2 and tier 1	100
	Washing capacity>3.5 kg, tier 1	200
Double barrel impeller	Tier 2 and tier 1	70
Drum	Tier 1, Washing ability≥1.03, Water consumption≤10 L/cycle/kg, Energy consumption≤0.17 kWh/cycle/kg	260

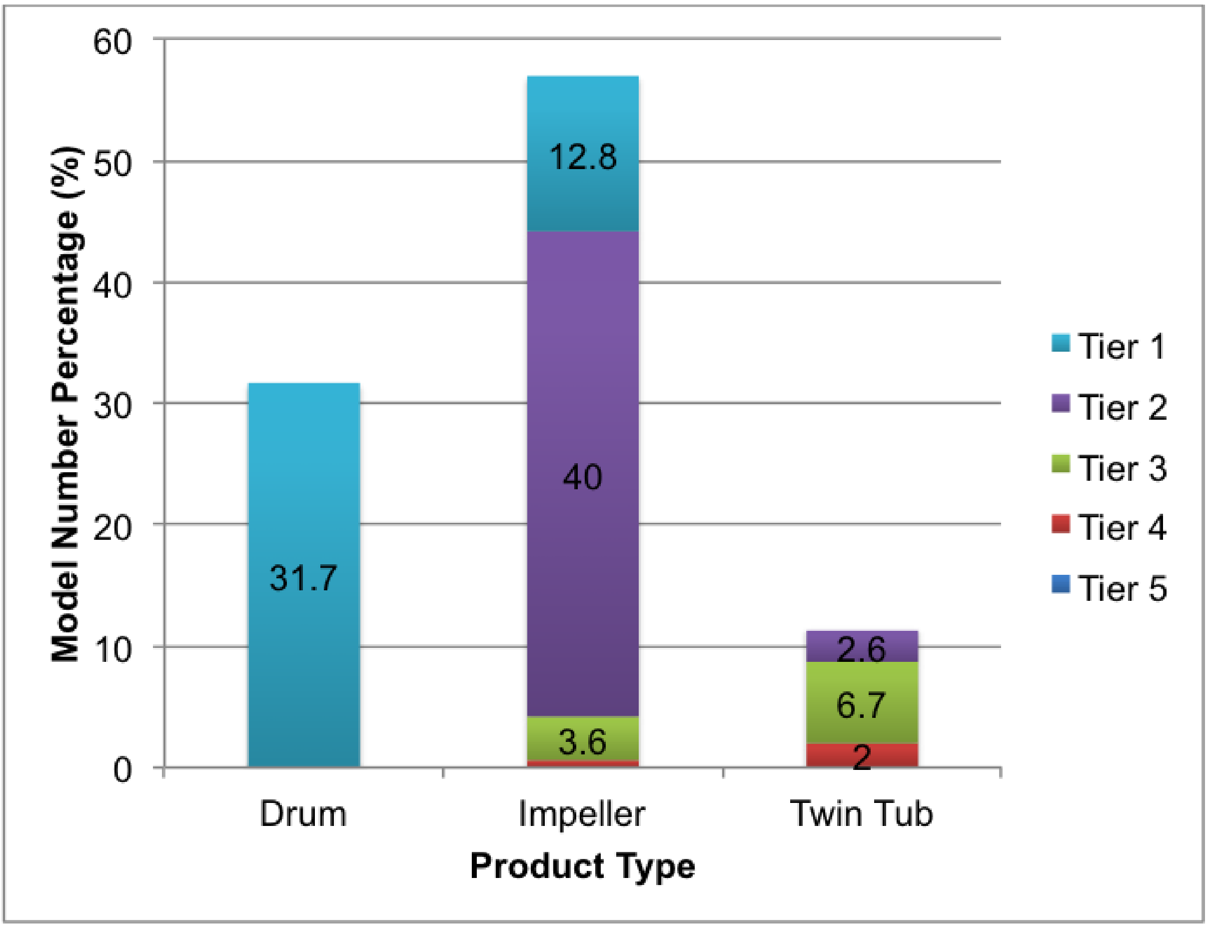

Figure 7: Energy efficiency tier share in different product types

Figure 7 shows all the drum washing machines are tier 1 products, while 25% of the impeller washing machines are tier 1 products. Taking tier 1 and 2 as the energy-saving products which is defined in the standard, there are more than 85% of washing machines that are energy-saving products. Resetting of the MEPS and energy efficiency classification of the washing machine is urgently needed.

Water heaters[11]

The latest subsidy program includes three kinds of water heaters: 1) Gas water heaters, 2) Solar water heaters, and 3) Air-source heat pump water heaters. It was encouraging that the electrical water heater was excluded from the subsidy because such kinds of products waste energy by multiple transformations (coal to electricity, electricity to heat). We found that the subsidy scheme was established before the minimum energy performance standard for air-source heat pump water heaters was available. This implies that the standardization work is sometimes behind the policy and the process time needs to be improved. Due to the current limited data and page, more detailed discussion about this product can be seen in our specific report.

Conclusions

This paper reviewed the latest subsidy program for energy-saving products in China, and analyzed the subsidy schemes for the five target product categories based on a market analysis. Due to the data limitation, we cannot see the full spectrum of the truth, but based on our existing analysis we still arrived at the following conclusions:

1. MEPS need to be revised soon. On one hand, the market share of tire1 models is too high to determine the high energy efficient products, on the other hand, the recent subsidy program needs a more stringent standard to regulate the energy-efficient appliances market. Technology-neutralism is needed to have lowest energy consumption when we receive the same services. In addition, the energy consumption information shall be visible on the energy label to ensure customers have options to select energy-saving products.

2. It is recommended that the new MEPS replace the last tier with a meaningful value according to the models distribution of energy efficiency tiers, and reclassify tier 1 accordingly. We also proposed possible plans, for example reclassification for refrigerators is given based on EEI distribution and the subsidy scheme.

3. The effectiveness of the subsidy program can be improved given the following advices: from the energy saving perspective, subsidies shall only go to top-efficient necessary products (follow the rules of both efficiency and sufficiency), i.e. no wrong signals shall be given to consumers to get the maximum subsidy and buy a big-sized product which is unnecessary, otherwise “Jevons paradox” might happen. Therefore high absolute energy consumption modes (even if it is very efficient) shall not be subsidized; High-end models and luxury products shall not be subsidized, instead, to promote energy-saving technologies for mainstream models, subsidies shall intensively go to those models that have small and medium size. (this statements is from our point of view of saving energy, not considering the economic effect)

4. Many products in Tier 1 and Top10 are made artificially expensive to profit from affluent customers. This needs to be stopped. Subsidy should only go to end-consumer, not manufacturers.

5. To ensure an effective implementation of the energy policies, more enforcement and monitoring measures need to be taken. Tolerance is strongly recommended for the evaluation of the difference between the tested parameter values and the required or declared values, especially during subsidy registration.

Acknowledgement

We thank Mr. Conrad U. Brunner for his insights and guidance, we thank Mr. Zhao Zhonghua for his guidance and support, and we also show appreciation to Mr. Stuart Jeffcott for his comments.

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[11] http://www.sdpc.gov.cn/zcfb/zcfbqt/2012qt/t20120608_484891.htm

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Number references in the text in square bracket. Use “references” style here or Arial 10 justified single space. After each reference skip one line (inbuilt into style). See the examples below

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A Review of the Concept of Energy Service Efficiency as a Metric for Assessing the Provision of Energy Services in Residential Buildings

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Abstract

Energy is used in buildings to provide multiple services such as illumination, comfortable temperature, sustenance, hygiene, communication and entertainment. This paper considers the potential methods and metrics for developing a framework to quantify the efficiency of delivered residential energy. If it were possible to provide these same services at the desired levels in more energy-efficient ways, the result would be lower emissions of greenhouse gases without a reduction in welfare of the building occupants. This paper develops the ideas of energy service efficiency as a more rigorous metric by which to choose appropriate low carbon technologies and energy efficiency measures.

The generally accepted engineering definition of energy efficiency as the ratio between useful output to energy input has been studied. The chain through which energy is transformed from primary energy to final and useful energy has been scrutinised under 'energy input', while the metrics for measuring the output have been examined in detail. This will lead to a better understanding and higher level of rigor in the analysis of the concept of service efficiency. Although the concept of energy services has long been considered, there is a dearth of literature focussing on methodologies for measuring the delivered service and on metrics for comparing efficiency.

This paper works towards establishing a tool for future assessment of the performance of low carbon technologies and practices such that the most appropriate options can be applied to individual buildings. The focus is on residentialenergy services, but the approach could subsequently be extended to other services.

1. Introduction

It is increasingly being recognised that the traditional focus for energy planning solely on the energy supply systems has resulted in a limited view of the potential for energy reductions [1], [2]. Expectation that supply can continue to meet an increasing demand lacks the reality that the majority of energy supply worldwide continues to be reliant on fossil fuels, supply of which is not unlimited and results in more intensive and controversial methods of extraction such as tar sands and arctic drilling. With better consideration of the demand side, greater potential for a drastic change to energy systems may be possible.

Energy demand is not a demand for fuels or electricity, it is driven by a demand for the services which energy can provide – comfortable rooms, illuminated spaces, sustenance, hygiene, mobility, entertainment [3–5]. Daly [6] described the 'ultimate end' of these services as 'want satisfaction' and Nørgård [7] extended the full energy chain beyond energy services through 'lifestyle' ('the system in which people organise society and daily behaviour in an attempt to satisfy their needs…constrained by the frames provided by the natural environment and society') and 'welfare' ('well-being, quality of life…the ultimate end of satisfying people's real needs and wants').

The concept of energy services is not novel, and it has formed a part of the business model of energy service companies (ESCos) and energy performance contracts (EPCs) since the early 1990s [8–10]. However, the method of measuring the efficiency of the delivery of energy services has still not been fully developed.

This paper provides the justification behind a new type of metric for assessing the performance of technologies and energy efficiency measures (design and control can also improve energy performance but are not specifically technologies). It is a framework through which different technical, design and operational configurations could be assessed, with the intention of developing the concept of energy efficiency to a more meaningful consideration of the energy required to deliver what people want and need to satisfy their welfare.

In order to identify the potential for this area of development, the concept of service efficiency requires more thorough analysis. This paper provides a review of the work done surrounding this area of research and combines the ideas to present a new methodology for assessing the efficient delivery of energy services. The concept of energy services are introduced in section 2 and the chain of the energy system which goes to delivering these services is discussed in section 3. In section 4, efficiency is explored, commonly defined as a ratio of output to input or the proximity that a system is operating relative to maximum potential. This leads into section 5 which starts with a literature review of the concept of energy service efficiency before going deeper into the discussion of how the development of these ideas could improve upon current metrics for assessing technology and building energy performance. A framework for development towards a systematic methodology for the measurement of service efficiency is presented. Section 6 develops this broader discussion and finally section 7 is a conclusion including outline of further areas of work which would move this area of study towards achieving its goals.

2. Energy Services

Energy demand is not driven by a demand for commercial energy itself, but rather by a demand for energy services [3–5], [11]. The term energy services is well used in literature as 'the benefits that energy carriers produce for human wellbeing' [12]. By making energy service delivery the focus of energy use, there is greater scope for consideration of the reduction of energy use without an implicit reduction in welfare. When aiming for a more detailed way of defining energy services, a balance is required between qualitative and quantitative metrics such that the service demand can be most accurately defined but comparable between different methods of delivery. Energy services include mobility, thermally conditioned spaces, cold beverages, warm meals, food storage, hygiene, illumination, communication, entertainment and security.

As a society we have come to rely heavily on an unabated supply of energy to deliver these services. It is not only energy which goes to their delivery; water, materials, infrastructure and data are examples of other flows which are required and for this reason, Jonsson *et al*. [13] explicitly used the term services as opposed to energy services. However, energy is required in the delivery of all of these flows also, and therefore a consideration of the energy system is useful within this discussion as is given in the following section.

Of course, energy is not only used in society to deliver these 'direct' energy services. Some authors included physical structure - consumer goods, buildings, machines, steel making, tables [3], [4], [13], [14] – Haas [11] and Jonsson *et al*. [13] described these as 'indirect energy services' through which the embodied energy in all of the technologies, materials, structures and other objects we use and own can be accounted for. The field of Life-Cycle Assessment (LCA) has developed methods for including embodied energy and all lifecycle aspects of energy use and waste into analysis of energy impact. These can be extended to analysis of indirect energy services. Haas *et al*. [11] also discussed the idea that short term and long term components of service demand exist; choice of temperature setting, km driven and stand-by operation of a TV or computer are examples of short term service demand, whilst area of an apartment, size of car and number of light bulbs form the long term service demand.

3. Energy Chain

The energy that we use for the delivery of services comes from a long chain of transformations through different forms. The flow of energy is not a simple linear chain and there are feedback loops

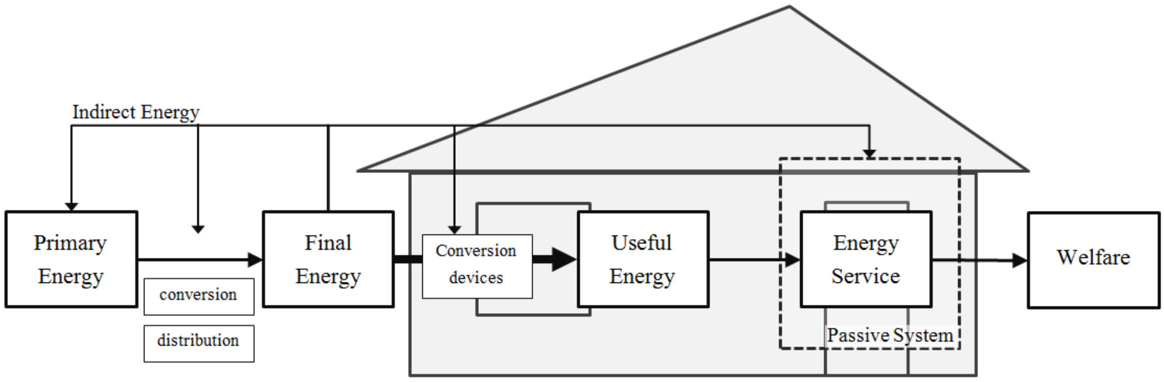

Figure 1: Energy system chain adapted from various sources [4], [7], [13], [14], [17], [18]**. The image of the house shows the split between on and off site stages, in this case suggesting the example of residential energy services.**

which need to be considered. **Error! Reference source not found.** depicts the energy chain and the parts along the chain are discussed below.

3.1. Supply Side Energy Carriers

Primary Energy

Primary energy is the term commonly used for the energy input to the whole energy system[15][15][15][15][15], most commonly from natural sources [4], [5], [7], [13], [15–20]. Conventional examples are fossil fuels (coal, petroleum, natural gas), other non-renewable fuels (uranium) and renewables (wind, sunlight, geothermal, hydropower, biomass). Waste may or may not be included as a type of primary energy carrier [21] and this definition will need to be agreed upon as waste to energy schemes becomes more common.

Final Energy

Final energy is the form of energy which is delivered to the end user or point of consumption [5], [17] such as electricity, natural gas, fuel oil, district heat, charcoal, petrol or diesel [4], [5], [7], [17], [18]. In the context of building energy use, final energy may either be centrally provided, such as grid electricity, mains gas and district heat, or it may be self-generated by an onsite technology such as a micro wind turbine or solar panel which converts primary natural energy (wind or sun) into final energy (electricity or hot water).

The term secondary energy is also commonly used in the literature, but the difference between secondary energy and final energy is not always clear. Some distinctions hold secondary energy as an intermediate energy carrier, where primary energy carriers are transformed, refined or converted into secondary energy carriers [7], [17], [22] which in many cases are *also* final energy carriers. Nakićenović *et al*.'s [23] distinction gave a more rigid distinction; that primary energy is transformed into secondary energy (eg coal to electricity) and secondary energy becomes final energy through distribution to point of use.

Within the building industry, the concept of 'Zero Energy Buildings' is gaining attention, for which on-site energy generation is equal to or exceeds the energy taken from the grid, over a year period. The 'net delivered energy', (energy delivered to site by energy companies less the exported energy from on-site generation) should not be confused with final energy as there will ordinarily still be significant energy consumption within a zero energy building and embodied energy in the construction [1], [24].

Useful Energy

Useful energy is heat, light or motion. Final energy is converted into useful energy in appliances [5], end-use devices [4], [17] or conversion devices and it is this form of energy carrier which goes towards delivering an energy service. Care must be taken in analyses as the term useful energy is also used synonymously with secondary or final energy, exergy or energy services [7], [20], [21], [25–27].

Indirect Energy

Currently, attention to energy efficiency tends to focus on operating energy, and although this is important, it must not occur at the expense of a greater increase in energy use at other stages of the life cycle. Jonsson *et al*. [13] proposed that the 'ultimate energy efficiency measure is to be able to provide the same [service] output without any input from the energy supply system', but this fails to take account of the input of indirect energy. As the energy used in operation decreases, the relative importance of embodied energy in all aspects of the production phase of technologies and energy efficiency measures increases and optimisation of design should be aimed at minimising the energy use over the whole life cycle [20], [28], [29]. Inclusion of these factors of indirect energy consumption is important for consideration of the full energy input to energy services.

3.2. Delivery of Energy Services

Most commonly, the focus of delivering energy services is on the conversion devices, defined as 'devices which transform or upgrade energy into more useful forms' [30]. However, it is the combination of delivering useful energy at the right time, in the right space that produces the required service. The idea that this space is important was a focus of the work by Cullen and Allwood in their analysis of the global efficiency of the flow from fuel to service [14] and they introduced the term 'passive system'. They described the delivery of energy services as being a two stage process whereby final energy was transformed or upgraded into useful energy in a conversion device and this useful energy is degraded and consequentially lost as low-grade heat within a passive system, in exchange for the provision of final energy services. Most literature has no inclusion of such a concept, but considerable improvements in the delivery of energy services can be made through improvements to the passive system; the requirement on room heating can be significantly reduced by improved insulation, as well as improvements to the heaters.

With regards to welfare, Daly [6] described the 'ultimate end' of these services as 'want satisfaction', and Nørgård [7] used the term 'welfare' as the 'ultimate end' after the intermediary 'lifestyle'. Welfare in this case means 'well-being, quality of life, or whatever terms have been applied to express the ultimate end of satisfying people's *real needs and wants*' [7 italics in original]. The inclusion of this step in the energy system represents the notion that the perceived need for energy services and the quality or quantity of service provided can also be a step for attention and optimisation. Optimisation in this case is not about maximisation but about sufficing people's needs.

3.3. Discussion

The breakdown of the energy system into the stages discussed in this section is useful when considering the energy input used in the equation for service efficiency considered later in this paper. Nakićenović *et al*.'s [23] analysis of the energy and exergy efficiencies at the different stages of the energy chain found that the main losses of energy and exergy occur at different points in the energy chain for different fuel types and although the data used would now be obsolete, the salient point is that comparison between different fuel inputs must reflect their relative efficiency of conversion through the whole energy chain.

For comparing the energy efficiency of whole systems - individual houses or single pieces of equipment - defining the boundaries is important for meaningful assessments. Considering different boundaries may highlight different opportunities for efficiency improvements. These boundaries should include the loops in the energy system whereby final energy is also required at every point along the chain and embodied energy is incumbent in all infrastructure of the chain.

This focus on energy input is important for thorough analysis of energy efficiency which is discussed in the next section.

4. Concepts of Efficiency

The term "energy efficiency" is 'widely used but not always well understood' [31]. It is used to represent how well a system is performing; the manner or quality of functioning or the extent to which a desired effect is achieved [1]. Quantitatively, it gives the ratio between input and output energy (or other measurable quantity), or the ratio of actual result to the best theoretically achievable result. These different approaches to a measurement of the performance of a system will be discussed in this section

Efficiency can be considered and assessed at different levels from the micro scale across a single piece of technology or energy efficiency measure, at a meso level across a whole house or community, or at a macro level at a national or global scale.

4.1. Efficiency as the ratio of output to input

In the field of engineering, energy efficiency is generally defined as the ratio of useful output to the energy input as shown in Eq 1.

$$\text{Energy efficiency} = \frac{\text{Useful output of a process}}{\text{Energy input into a process}} \qquad \text{Eq 1}$$

A similar metric is energy intensity, or specific energy consumption (SEC), which is the inverse of efficiency and represents the input of energy required to achieve a useful output as shown in equation**Error! Reference source not found.**.

$$\text{Energy intensity or SEC} = \frac{\text{Energy input into a process}}{\text{Useful output of a process}} \qquad \text{Eq 2}$$

These metrics are related to the first law of thermodynamics, that within a closed system, energy is conserved. Energy efficiency in this form shows the proportion of energy input which is converted to the desired output. Thermodynamic energy efficiency would have an output measured as energy, although other useful metrics involve a different output metric such as those indicative of a service delivered (mass of product, square metres of floor area or passenger-km), or an economic variable such as GDP; Patterson [32] termed these physical-thermodynamic and economic-thermodynamic indicators respectively.

The input measured can have an effect on the value of efficiency calculated depending on where the boundary of the system is defined. The energy may be measured at different points in the supply chain as discussed above; final (site) energy, delivered energy, primary energy, and may or may not include indirect (or embodied) energy [1], [18].

The type of metric measured can alter the insight gained from the efficiency term. Consideration of exergy as well as energy can give more meaningful analysis of the appropriate energy quality being used. Exergy is a thermodynamic quantity which represents the 'quality of energy' and includes the concept of the change in entropy from the second law of thermodynamics. Exergy is defined as the maximum amount of work which can be produced by a system as a consequence of it not being at stable equilibrium with some reference environment [33]. Unlike energy, which according to the first law of thermodynamics is conserved across a system's boundary, exergy is not conserved. When considering efficiencies of energy systems, exergy takes into account the quality of the energy carrier and accounts for the fact that electricity has more potential for doing work than low temperature hot water which can only be used for heating purposes [15]. The second law indicates that although it is possible to achieve full conversion of work into heat and internal energy (through dissipation), exergy losses in combustion and heat transfer contribute to poor thermodynamic performance [34]. In many cases, exergy efficiency is lower than energy efficiency, indicating that improvements could be made in terms of matching energy input to energy output. [35], [36].

4.2. Efficiency as the proximity to best theoretically achievable result

An alternative efficiency metric provides a measure of the actual input compared to the minimum input that would be required in the ideal case and therefore providing an indication of the proximity to the ideal system. This is referred to as second law efficiency when exergy is considered and incorporates the idea that exergy is not conserved and the quality of energy is degraded through conversion processes. When addressing the performance of a system, a baseline is useful for comparison to an ideal value to give an idea of potential for improvement. **Error! Reference source not found.** shows the generalised case (where input may be energy or exergy or some other input).

$$\text{Efficiency} = \frac{\text{Minimum theoretical input required}}{\text{Actual input}} \qquad \text{Eq 3}$$

Examples of the use of second law efficiency are found by Ayres [37] and Nakićenović [38] and Perez Lombard et al. approached the energy efficiency of heating system as the 'thermal energy virtually needed (ideal demand) to the final energy actually consumed', showing the use of a similar approach for efficiency as ideal energy demand to actual energy use.

Cullen and Allwood [14] calculated an estimate for the potential for energy savings in the global energy system by calculating the difference between current and target efficiency as shown in equation Eq **4**.

$$\begin{matrix}\text{Potential for}\\ \text{saving energy}\end{matrix} = \begin{matrix}\text{Scale of}\\ \text{energy flow}\end{matrix} \times \left[\begin{matrix}\text{Target}\\ \text{efficiency}\end{matrix} - \begin{matrix}\text{Current}\\ \text{efficiency}\end{matrix}\right] \qquad \text{Eq 4}$$

The target and current efficiency terms were measured as a 'utilisation ratio', calculated as the ratio of energy input to service output, and this shows an approach for using efficiency terms which combine the two alternatives above. This difference between target efficiency and current efficiency as an indication of the performance of the system allows identification of areas where current performance is sub-optimal and for energy efficiency improvements to be focused.

Other definitions of improved efficiency are achieving the same level of output at a reduced energy consumption, or an increased level of output for the same energy consumption [32], [39], [40]. The latter definition may signify an improvement in energy efficiency but not in energy consumption [1] and is related to the Jevons Paradox, or the rebound effect [41–44].

4.3. Considerations for measurement of efficiency

The '*where*, *when* and *how* … input and output [should] be measured and valued?' [13 italics in original] needs to be considered when accurately trying to define energy efficiency, and encompasses several important factors as listed below [1], [13], [45] and any assumptions should be clearly stated;

- the system boundaries,
- quality judgment of delivered output
- types of energy, quality of energy and units of measurement,
- method of determination (measured or estimated),
- temporal characteristics (static or dynamic)
- baseline (best theoretical, best practise or the performance of similar systems in other locations or at other times in history)

The evaluation of the efficiency of an energy system has been attempted on micro, meso and macro scales, for each of which a different methodology is suitable. The efficiency term is only as useful as the data available for its evaluation and often economic or supply side efficiency measures are favoured, particularly on macro national or global scale as this data is more widely available and comparisons can be made across regions. However, the temporal variation of monetary value means this is less useful at a micro scale [32], [40], [46] and limited insight can be gained into the current performance or potential for improvement and therefore new metrics for energy service would be valuable for the improvement of technology or building assessment.

4.4. Discussion

Of the approaches to energy efficiency discussed above, both present valuable information on the performance of a system. It is helpful to include explicit information of what the input and output of the system are, but this needs to be supported by details of what boundary is being used and what type of input and output are being measured. It is also useful to include an indication of how close a system is performing compared to its optimum as this gives the calculated value context. Ideally, a combination of the two types of indicators included above would provide context and clearer identification of where priorities for energy efficiency improvements should be concentrated.

5. Energy Service Efficiency

Energy efficiency has been extended to "service efficiency" in a number of publications. Daly [6] used the term "service efficiency" in his equation to describe 'ultimate efficiency' as 'getting more service per unit of time from the same stock[1]'. Patterson's [32] 'physical-thermodynamic indicators', and Haas *et al.*'s [11] term 'technical efficiency' both gave a measurement of a specific energy service per energy input. In other cases, the inverse is used; Pérez-Lombard *et al.*'s [47] definition of energy intensity, and Cullen and Allwood's term 'utilisation ratio' calculates the ratio of energy input to service output. Other publications have given equivalent definitions of using less useful energy without a loss of service quality [7], [13], [17]. The most common metric of energy service efficiency is the energy service energy intensity (the inverse of efficiency) as shown in equation 5.

$$\text{Energy Service Energy Intensity} = \frac{\text{Energy Input}}{\text{Service Output}} \qquad \text{Eq 5}$$

Ayres [37] uses the terms second law efficiency and service delivery efficiency synonymously in his analysis of the UK energy system as the difference between current and ideal maximum efficiencies. This was a similar approach to that used by Cullen and Allwood [48] for the estimation of the practical limits of energy reduction in the global energy system as discussed above. These show the approach of efficiency as a measure of proximity to the ideal system.

For use as the output term in a service efficiency metric, the quantification of energy services is necessary. Quantification requires the measurement of a suitable magnitude of demand indicator which involves the definition, assessment and analysis of a set of energy efficiency indicators (as discussed in the following section). In previous literature, measures of service efficiency similar to Patterson's [32] physical-thermodynamic efficiency indicators have been used where the service demand is measured in terms of capita, households or people. Cullen and Allwood [14] go beyond this and use units of final service of cubic metre-Kelvin of air for thermal comfort, or hot water and Newton-metres of work for hygiene, Joules of food for sustenance, lumen-seconds for illumination and bytes for communication. Other 'energy efficiency indicators' can be found in the literature, which appear to take the form of the above mentioned ratios and have been developed for the assessment of energy performance and for quantifying the success of energy efficiency improvement measures. **Error! Not a valid bookmark self-reference.** shows a broader range of such metrics found in literature and existing databases for describing energy efficiency by end use. The term 'energy efficiency indicator' is used in the literature, although the form of the indicators is the inverse of the efficiency and therefore technically a measure of energy intensity.

Table 1: Energy efficiency Indicators by End Use in Literature and Existing Databases

Service	Energy Efficiency Indicator	Measurement	Ref
Thermal Comfort	Unit Consumption (UC) per floor area for space heating	toe/m^2	[49]
	UC of useful energy per dwelling for space heating	toe/dw	[49]

[1] where 'stock' is the constant content of a steady state economy eg constant physical wealth and material artefacts

	UC of useful energy requirement per m^2 for space heating	toe/m^2	[49]
	UC of useful energy for space heating per degree-days	toe/dd	[49]
	UC consumption at constant structure of heating system	toe/dw	[49]
	UC per floor area per degree day for space heating	kJ / (m^2 . dd)	[50]
	UC per floor area per degree day for air conditioning	kJ / (m^2 . dd)	[50]
Illumination	Electricity per m^2 floor space for lighting	kWh / m^2	[51]
Sustenance	UC per capita for cooking UC per dwelling for cooking Specific Consumption (SC) for refrigerators, freezers, UC for refrigerator per litre	kWh or toe / cap kJ / dw (kWh/equi) kWh / litre	[49] [50] [49] [50]
Hygiene	SC for washing machines, dish-washers UC for washing machines, dish-washers UC per person	(kWh/equi) kJ / dw kJ / p	[49] [49] [50] [50]
Communication & entertainment	SC for TV, (other electrical appliances) UC for appliances	(kWh/equi) kJ / dw	[49] [50]

UC: Unit consumption, **SC:** Specific consumption, **kWh**: Kilowatt hour, **toe**: Tonne of oil equivalent, **dw**: Dwelling, **tCO_2**: Tonne of CO_2, **dd**: Degree-day, **cap**: Capita, **equi:** Piece of equipment **p**: Person

5.1. Measurement of Energy Services

When developing a metric by which technologies can be assessed for their service efficiency, the starting focus should be the desired service output. The above metrics go some way towards this, but they don't fully capture the extent of the required service and work in this area could be valuable for the development of the concept of energy service efficiency. This aspect must be considered, giving attention to the precise service required and the comparability of service delivery methods needs to be considered. For example, there is potential to further develop a metric for thermal comfort to occupied spaces not only being at a desired temperature, but more specifically that spaces in the building are at a specified temperature for the time that they are occupied. Overheating or overcooling any area, or heating or cooling unoccupied space, would be a waste of useful energy. Equally, a current measurement of chilled refrigeration space as litres of chilled storage doesn't address cases of a household having a large fridge when a smaller fridge would suffice for the service of 'chilled storage for the household's required food'.

A good example of how the definition of energy services can alter the approach was given by Haas *et al*. [11] in the contrast between the services of 'mobility' and 'transport'. They put that a common and more technical definition of 'transport' considers the energy service 'to reach the office' for which the aim would be to provide this 'distance travelled' with as low an energy input as possible, whereas 'mobility' considers the energy service 'to reach the shop where I can buy a certain product', which allows other possible approaches to reducing the energy input such as through alternative infrastructure (taking a bus or buying the product on the internet) or special planning (stopping at the shop as part of an existing journey). When comparing an inefficient bus in Delhi to an ultra-efficient sports utility vehicle, the Delhi bus is more efficient at delivering service quantity in terms of energy per passenger-km, but the quality of service is not equivalent [11]. Conversely, conservation measures for a car journey - improved use of the car, traffic conditions, walking, or replacing the journey with a phone call – could deliver the same desired service with less energy requirement, depending on the purpose of the journey [17].

This gives rise to the question of comparative services where by different means for service delivery can be compared. Jonsson *et al*. [13] discuss the potential for reducing the required energy input whilst maintaining the same 'experienced utility and quality of service'. They presented a rigorous qualitative framework for approaching service through four underlying of *volume*, *content*, *quality* and *motivation* to suggest an approach for 'complementary views' of the service delivery which would have a lower energy demand.

- **Volume**, as the underlying 'quantifiable amount of energy service delivered' such as passenger-km for transport and area of thermally conditioned rooms
- **Content**, as the 'experienced utility of service' such as thermal comfort or commuting to work
- **Quality**, as the 'experienced reliability, accessibility, safety and security, convenience and ease' such as acceptable journey time, ease of control panel for heating system or reliability of electricity delivered from the grid
- **Motivation**, as the reason for 'why a service is called upon in terms of practical (those which sustain comfortable everyday life), symbolic (those with symbolic value which support a certain lifestyle) or aesthetic (those which convey feelings of wellbeing to an individual) reasons

Due to the complexity of valuing the output of a service, tied into consideration of varying perceptions of 'quality of life', 'lifestyle' and 'welfare', they suggest that 'service should be considered quantifiable only in part'. They advocate for a broader interdisciplinary systemisation, focusing on why the service is called upon, but this qualitative aspect introduces complexities when trying to integrate service efficiency into a modelling context. Pérez-Lombard et al. [47] reinforced this point, highlighting the difficulty in quantifying the very diverse range of activities which services encompass, and they suggest the differentiation between quality and quantity. They suggest that energy efficiency indicators of any system or device are best sought in a case by case basis. The concept of analysing comparative methods of service delivery confers with Nakićenović's [17] argument that energy reduction requires not only 'the reduction in specific energy needs for performing a given task', but 'the reduction in energy needs due to changes in the nature or level of the required energy services' (which he defined as energy efficiency and energy conservation respectively). A reduction of level of energy service is unlikely to be popular with the general society unless it can be perceived that this level of service is chosen and therefore the focus on the change in delivery method is beneficial.

In order to compare service efficiencies, either to a maximum potential or when comparing the efficiencies of different technologies or measures, it is important to explicitly identify the service which is being compared. When comparing different systems to deliver a common output, it is beneficial to have a definition of a 'service unit'. As in the work by Cullen and Allwood discussed above, the service is defined in base SI units, but there is potential to develop these to match more closely the services people require, for a micro bottom up analysis or for use as efficiency indicators on a building level.

A ‘service unit’ could be defined for each service. This would be equivalent to a functional unit defined in life cycle assessment (LCA) as the 'quantification of the identified functions (performance characteristics) of the product basis for comparison for alternative goods or services' [52]. As with the functional unit in LCA [53], the service unit should relate as closely as possible to the function or service i.e. rather than a technology or energy efficiency measures being assessed on heating a square meter of floor area, it should be assessed on how well it can maintain an area of a certain type[2] for a given period at a desired temperature. This would enable comparison between different delivery methods, such as heaters, insulation or a given combination, based on this equivalent service requirement. Similarly, using a service unit for clothes washing as 'kg of clothing' does not account for

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[2] Factors such as height of ceiling, or type of space (room, corridor, outside area) may lead to different options performing better in different situations

the variation in washing requirements of different types of clothing of different weight; a more appropriate service unit would be 'a cleanly clothed person for a given duration'.

5.2. Development of Energy Service Efficiency Metrics

In order to extend the concept of energy services to being commonly used in the performance of technologies and buildings, development of this work is required. If it is energy services we desire, then surely buildings should be designed to deliver energy services and assessments of buildings and technologies within them should be assessed directly related to these. Ideally, a metric of energy service efficiency, or as is shown here, the inverse of energy service efficiency (energy service energy intensity), could be developed relating to a more precise energy service required and this service unit could be a common point of comparison for different technologies or other energy efficiency measures; both conversion devices and passive systems. For the application to a building performance metric, the level of service unit demand for the different services could be multiplied by the energy service energy intensity to evaluate the energy input required by a building, as given in Eq 6.

$$\underbrace{\frac{\text{Energy Input}}{\text{Service Unit}}}_{\substack{\text{Energy Service}\\ \text{Energy Intensity}}} \times \text{Level of Service Unit Demand} \;=\; \text{Energy Requirement} \qquad \text{Eq 6}$$

As the ‘service unit’ metric in the efficiency equation gets more defined, characterisation of service demand becomes more difficult, but this approach is necessary in order to overcome the rebound effect such as that as energy per square meter of heated space or litre of chilled storage reduces, the demand for these aspects of service decrease.

However, with a miss-defined metric of service, this approach would be susceptible to a rebound in service demand with less energy leading to an ever increasing demand for house size and appliance size and therefore the right definition of services is important.

This methodology could lead to a new approach for energy service companies (ESCos) in which the customer pays for their demanded services. ESCos (or energy performance contracting as it is commonly sold as in the UK) has become more closely about selling energy efficiency measures rather than selling services, and the better quantification of energy services and associated efficiency metrics could allow this. The metric of total service demand could give freedom to an occupant to stipulate the service which they demand, i.e. the areas which they want thermally conditioned or illuminated, and at what temperature or light intensity, or the clothing regime which they prefer. This would allow greater flexibility that the current approach in which an 'adjustment factor' to accounts for changes in the service required, but in general it is assumed that the service demand will stay constant[3]. There are particular difficulties if the service demand changes or if historic data is not available, which is particularly prevalent in the residential sector, and this alternative methodology would allow for the consumer to specifically choose the level of service which they desire and pay for these services.

6. Discussion

The aim of this work is to produce a metric for the measurement and evaluation of the efficiency of delivering energy services; the energy service efficiency. This would be a valuable metric for assessing the performance of low carbon technologies and other energy efficiency measures acting as conversion devices and passive systems in delivering energy services.

Any measurement of energy service efficiency should be based around the energy service required. This would be most conveniently addressed by considering service units, equivalent to functional units used in LCA. Previous work in this area has used service definitions such as ‘squared metre of heated area’ , ‘litres of chilled storage’ or ‘kg of washing’, but there is potential to improve upon these

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[3] The adjustment is also used to account for weather variation, particularly relevant to energy consumption in heating, using the concept of degree-days

metrics in order to most closely match the service measured to the service required and reduce the potential for rebound in the increasing demand for services. For example, a measure of sufficient clothing for a person for a week instead of kilograms of cleaned clothes for hygiene or sufficient food for a household instead of kilograms of cooked food for sustenance. The definition of these service units should consider the service being provided and the motivation for this service demand, the quality of service which is required and consideration of the time period over which the service is demanded may also be relevant. A meaningful quantification of the service required, including details of these aspects, would form the energy service demand metric. This metric would not be directly comparable for different services, but would provide the basis for comparison between different technologies and energy efficiency measures.

With the energy service defined and the requirement of useful energy input and schedule of operation determined, technologies or measures can be compared based on their energy, exergy or other inputs, or their related environmental impact such as CO_2 emissions. For meaningful comparison, the boundary over which the inputs are considered must be consistent; the use of final energy rather than primary energy would give different, potentially misleading, results over the whole energy system. The inclusion of indirect energy will help to build a more thorough comparison of the overall energy input to each technology or energy efficiency measure for delivery of the defined energy service.

Assessment of technologies and measures should include aspects of actual performance as used as opposed to only rated performance in laboratory tests, and the ease with which it can be installed and operated. Existing approaches to rating individual technologies exist, whereby technologies are assigned 'energy labels' based on the performance of the technology in a standardised test [54]. These test procedures measure the performance of the appliance under steady state in a controlled environment at the beginning of the product's life time [55], [56]. Meier [56] stated that 'every test procedure is a compromise' as the goals for an 'ideal test procedure which reflects annual usage conditions without compromising on reliability and cost effectiveness' are contradictory. However, in order for the concept of energy services to proliferate, an alternative assessment approach would be required which more accurately rates the technology based on the service which it is required to deliver. The methodology could also lead to a new approach for energy service companies (ESCos) whereby the customer pays not for the electricity and gas they consume but for the demanded services.

The work presented in the previous section provides a methodology through which the total energy demand of a building could be calculated based on the level of energy services desired by the occupants. This could provide an aggregated measure of the performance of delivering services for a whole house. This approach has the potential to be extended in order to provide a more rigorous method for assessing the energy performance of a building than the current approach using Standard Assessment Procedure (SAP) or Energy Performance Certificate (EPC). This micro scale approach could also be extrapolated to give an indication of the service efficiency on a national scale, but the inherent inaccuracies in these approximations should be recognised.

For a better metric of energy performance of a building to be developed, a more detailed reporting of what, where, when and why energy is being used would be highly valuable, and could provide a real-time indication of how well a building is performing compared to a modelled optimum. It would require heavier data collection than some metrics, but as the availability of smart metering and sub metering improves, and data processing becomes more effective, this will become less of a barrier the future.

Expected levels of service are a function of culture and lifestyle; by minimising energy service demand, significant levels of energy can be saved. The perception of this effect on welfare can be influenced by psychological means such as whether the change in energy service level is perceived as chosen or forced.

7. Conclusion

Faced with the challenge of shifting an existing well established energy system from supply focused to demand focused, this paper has considered some of the important issues related to the concept of energy service efficiency.

In the case of both energy efficiency and energy service efficiency, two types of metric were identified; a ratio of output over input, and a ratio of current demand compared to the minimum demand in the ideal case. This paper focussed mainly on the former case, exploring the stages of the energy chain from primary energy to welfare including the importance of considering indirect energy as well as direct energy and considering aspects for the quantification of energy services. In the latter case, the ideal maxima may be calculable for a given service, and a comparison to these would be useful to put into context how well the system is performing. However, when comparing services, it should be done on an equivalent basis regarding the quality as well as quantity and Jonsson *et al*'s [13] framework could be a useful guideline for this.

The existing quantified approach to demand side measurement in literature and national statistics, typically giving energy consumed per end use, is somewhat limited in its approach to actually addressing why energy is used. Conversely, the ideal approach to assessing energy service demand is qualitative and difficult to quantify. This work goes towards bridging this gap and developing a more rigorous quantitative approach.

Further work is required in the development of this area to turn the concept into a useful model such that data from upstream in the energy chain and metrics for the quantification of service delivery can be fed in and meaningful service efficiency results be calculated. The next steps are to bring together required energy input for point of use and embodied energy for all technical options for energy service delivery and link them to the service which they can provide. This could be integrated into new or existing building modelling packages to make them more explicitly apply the theory of energy services to building performance analysis. It could also give a better method for recommending the most appropriate technologies for delivering energy services.

This paper has not looked into the link between energy service and welfare however, but this link should not be overlooked as a reduction in demanded energy services would lead to a reduction in energy consumed overall. Determination of service can be taken from standards, but this average does not reflect the wide variety of people's needs and wants. As of yet, a method for using the concept of energy services has not been flexible enough to fully replace the traditional view of energy and this would be valuable work for the transition to a sustainable energy system in the future.

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The benefits of creating a cross-country data framework for energy efficiency

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Abstract

As manufacturers now sell a similar range of consumer electronics and home appliances to major markets around the world, the task of identifying a product's energy efficiency rating has usually been the responsibility of each country and its respective government agency. This has led to a multitude of energy efficiency testing procedures, ratings, and certifications, resulting in disparate data being captured on identical products. Furthermore, lack of consistent product identification criteria means product energy performance is not easily connected to relevant information about the product such as market availability, price or real world energy consumption.

This paper presents a new data standard for reporting energy performance and related product information that can be adopted internationally. To inform the development of this standard, we explore the existing energy efficiency market data for the two example products of TVs and Room Air Conditioners. This paper discusses current/future use cases of appliance level energy efficiency data across all stakeholders, including consumers, retailers/manufacturers, global standards organizations, third party service providers, and regulatory agencies. It also explains the key benefits of moving to a common international data framework for energy efficiency, such as: 1) a centralized product information repository for comparing energy use, ratings/certifications, and pricing data 2) improved access to relevant consumer electronics and appliance data to facilitate new policy development and harmonization across markets 3) enablement of retailers and other third parties to embed actionable energy efficiency information as part of the consumer experience.

1. Introducing a Cross-country Data Framework for Energy Efficiency

Among the most useful tools in the development of effective consumer electronics and home appliances efficiency programs and promoting consumer awareness of efficiency are data that allow for:

- Linking consumer retail information to efficiency parameters more effectively.
- Tracking efficiency trends over time (monitoring) and comparison of efficiency in different markets and jurisdictions (benchmarking).
- Tracking retail prices of appliances over time, and between countries.

Currently, broad access to consumer electronics and home appliances efficiency and price data and comparability between markets is imperfect. Product energy use labels, in countries that require them, are often not prominently displayed on sales websites; and in many cases it is difficult to access detailed product energy rating information. Policy makers must invest significant time and money in collecting data about the market status of the efficiency of available products when determining appropriate levels for energy efficiency policies. In addition, comparability of attributes across markets is often difficult, even for identical products, due to inconsistencies in model identifiers and efficiency metrics and protocols. A well-defined *data standard* for appliance attributes and efficiency characteristics could potentially solve this and many other product energy information access problems.

Key objectives of the data standard include: (1) development of internationally compatible data specifications for populating, retrieving, and cross-referencing data from web-based product databases and (2) definition of standardized methods for populating these product-specific databases. Data sources may include the use of product certification databases (such as those maintained by agencies that administer energy labeling and minimum performance standards programs); software tools (e.g., “webcrawlers” to gather and regularly update product-specific availability, efficiency and pricing data); and guidelines for the gathering and reporting of actual field (on-site) data on product energy use.

This paper outlines a proposed data framework for consumer electronics and home appliances energy performance and cost data being developed as part of the Super-efficient Equipment and Appliance Deployment (SEAD) Initiative of the Clean Energy Ministerial.[1] The goal of this project is to publish a data standard that can be implemented by relevant organizations that collect and store data about the energy performance, market availability and costs of energy-consuming equipment and appliances. This data standard can be used for sharing data among relevant organizations, and in the development of databases that store and analyze this information.

The data framework relies on two main data source types and anticipates a high degree of data collection automation. Product model lists are collected directly from retail websites, using online shopping application programmer interfaces (APIs). Connection to these online data feeds enables automated downloading of product model numbers, many product attributes and current retail prices. The second dataset type consists of efficiency certification databases, often maintained by regulating bodies responsible for minimum energy performance standards (MEPS) and labeling programs.

The combination of these two datasets provides a wealth of new information. The correlation of models found on retail websites with those in efficiency databases provides a time-dependent picture of the distribution of efficiencies on offer. These data could be updated frequently (perhaps daily), creating a high temporal resolution picture of the evolution of the market. Finally, datasets collected in this way can be used to compare the market for efficiency in different countries. By connecting real time prices with efficiency ratings and market share for the same product sold across markets, there is the potential to compare the cost consumers are willing to pay for efficiency across markets. This step may require robust algorithms for converting efficiency metrics between test procedures used in different countries.

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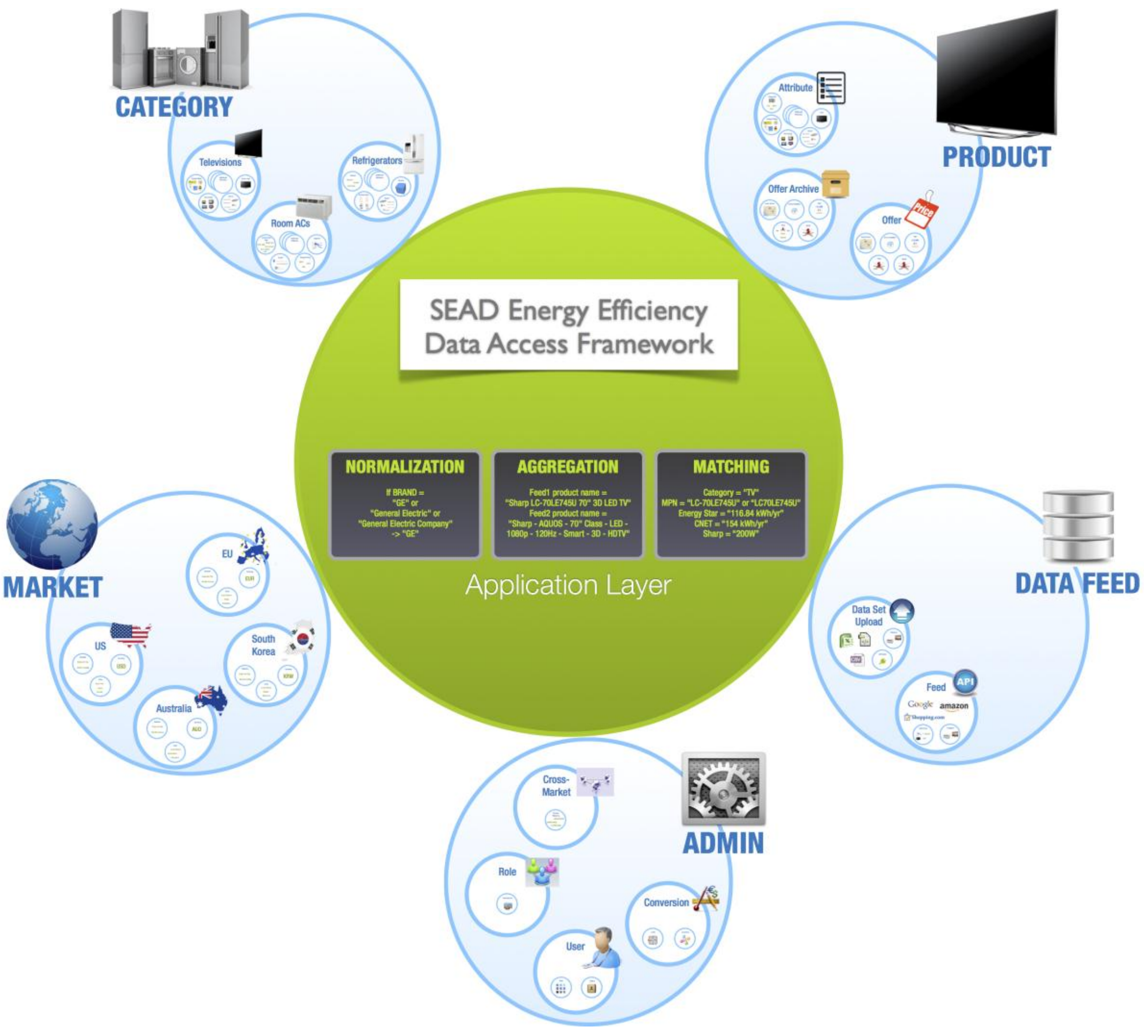
The following sections provide a detailed description of the framework developed as a pilot project supported by the U.S. Department of Energy as part of the SEAD initiative. We then consider two products – room air conditioners (Room ACs) and televisions (TVs) – as a test case to demonstrate the facility of the data standard. The paper concludes by considering applications of a fully implemented framework and discussion of implications.

2 Defining the Framework and Data Standard

2.1. Overview

The SEAD Energy Efficiency Data Access framework was designed to be able to capture and compare energy efficiency product data for the many types of consumer electronics and home appliances that are sold around the world. It uses a product-centric model with an extensible design to ensure that it can meet the requirements of any market or category. The core of the framework standardizes markets, brands, categories, product attributes, and units of measurement with common definitions. An intelligent application layer would connect with the framework to normalize, aggregate, and match data across the disparate energy efficiency certification and retailer data sources. The outcome is a new data standard that defines a methodology for capturing and sharing this data.

Figure 1 – Data Framework Conceptual Overview



2.2. Identifying Use Cases

To ensure that the new framework design could handle a wide range of potential use cases, feedback was gathered through surveys and interviews with the members of the SEAD Standards and Labeling Working Group, which consists primarily of policymakers from the 13 SEAD member economies. The outcome of the surveys and interviews was a prioritized list of use cases.

Table 1 – Prioritized Use Cases

#	Use Case	Need Type	Priority
1	Access to other countries' certifications and ratings for monitoring, verification, and policy design	Policy	High
2	Connect sales and efficiency trends	Policy	High
3	Ability to assess impact of marketing campaigns on consumer adoption	Policy	Medium
4	Enables comparison of product rating methods across countries	Policy	High
5	Facilitates procurement activities	Consumer	Medium
6	Enables development of consumer mobile apps/online comparison tools	Consumer	High
7	Facilitates product energy efficiency awards	Consumer	Medium
8	Facilitates utility incentive programs	Consumer	Medium
9	Enables comparison of testing procedures	Policy	Medium

Expressed needs broke down into two distinct categories: Policy and Consumer. 'Policy' refers to use cases that relate to analyzing, benchmarking, or creating appliance standards. 'Consumer' refers to use cases that enable consumers to have access to and leverage this data in their purchasing decisions. The overwhelming feedback was that this data standard should focus mostly on Policy development but also enable development of consumer mobile apps/online comparison tools.

2.3. Creating a Global Data Standard

An essential part of establishing a data standard is agreeing on a simple, consistent model that can be applied across diverse markets. To accomplish this task, the concept of a Global Category was developed which defines a universal set of product attributes that are gathered irrespective of the category. This is the mandatory information that will be captured for any category, covering the unique product identifiers, market, brand/manufacturer, pricing, energy, certification, and marketing related data.

Global Category Definition

To the greatest extent possible, the Global Category definitions have been based off of the IEA 4E Mapping and Benchmarking[2] and GS1 Global Product Classification (GPC)[3]. These existing definitions were chosen to facilitate harmonization of product category definitions across markets using international standards. Table 2 shows the proposed definition.

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Table 2: Global Category Data Standard

Attribute	Type	Notes
Manufacturer Part Number (MPN)	String	Product Model Number stripped of extraneous characters
Brand	String	Normalized Across All Markets
Manufacturer	String	Parent Relationship to Brand
Market	Code	Defined region based on ISO 3166-1 country codes
Global Trade Item Number (GTIN)	String	Universal Product Code (UPC) or International Article Number (EAN)
QR Code	String	Quick-Response Code
Price	Numeric	Min, Max, Mean, Median, and Standard Deviation of Daily Prices
MSRP	Numeric	Manufacturers Suggested Retail Price
Product Energy	Numeric	Operating and Standby Watts, Annual Energy Consumption (from a single data source)
Product Certification	Code, Date	Certifying Authority, Current Test Procedure, Registration Date
Product Images	String	Links to Images of the Product (multiple)
Product Marketing	String	Product Title, Headline, and General Description

Product Category Definition

While the Global Category attributes capture the common data across all products, it is also necessary to capture attributes specific to each product category, since the data required for TVs will vary substantially from that of Room ACs or Refrigerators. These category-specific attributes are the descriptors that bridge regional differences across markets. Below are examples of the TV and Room AC category definitions.

Table 3: TV Data Standard

Attribute	Type	Notes
Screen Technology	String	LCD, LED, Plasma, Projection, CRT
Functions Available	String	Analog, Digital
Screen Size	Numeric	Size in inches, centimeters, meters, or other unit of measurement
Resolution	String	HD or Conventional
Aspect Ratio of Screen	String	4:3, 16:10, 16:9
3D Ready	String	Yes, No

Table 4: Room AC Data Standard

Attribute	Type	Notes
Cooling Capacity	Numeric	BTU, kW, W
Refrigeration Method	String	Electrically driven, Absorption units
Condenser	String	Air cooled, Water cooled

Cooling		
Heat Transfer Fluid	String	Air, Water
Type	String	Unitary, Split units, Multi-split
Cooling/heating	String	Cooling, Heating, Cooling/heating
Variable speed drive/multi-speed compressor	String	Present or Not
Refrigerant	String	Refrigerant Type

2.4. Customization by Market

While the standard sets guidelines for which attributes to capture, it still allows for flexibility when implementing for a specific market. Each market using the framework will have the capability to add new attributes to an existing category or define a new category for products that are not currently covered. These extensions cannot be compared across markets.

Modifying a Category Definition

For example, some countries may want to classify types of Room ACs in more granularity and therefore there may need a 'SubType' attribute added to their Room AC category definition. Additionally, there may be a need to set up an attribute to capture a numeric rating that is assigned by a country's certification program.

New Category Definitions

It is also possible to define an entirely new category that is not currently covered by the data standard. This new category would automatically inherit the base attributes (such as MPN, UPC, or Brand) and would only need to have defined the specific attributes unique to that product category and market.

As more and more countries begin to adopt the data standard, the result will be that the majority of categories will have been standardized across all markets.

2.5. Methodology for Populating the Database Framework

To make the adoption of the data standard as seamless as possible, a comprehensive approach for populating the framework from existing data sources is detailed below. An application layer is required to normalize the disparate data across markets into the new standard.

A system using the framework would create unique products from online shopping APIs such as Google, Amazon, and EBay by pulling in product IDs, marketing details, technical specifications, and prices. Access to Amazon, EBay, and other international online shopping APIs is provided for all organizations that agree to be part of that retailer's affiliate network.

It would then match energy efficiency data based on MPN or GTIN via CSV uploads of certification data sets. An unlimited number of feeds from retailer APIs and certification data sets can be utilized in the framework to ensure strong coverage of each market.

Online Shopping APIs

Online shopping feeds from the retailers with the broadest product coverage will be utilized for creating a list of all current products on the market. One or many APIs per market will be accessed on a daily basis to pull the most up to date products and pricing data. The methodology for doing this as follows:

- Data feed retrieval: establish a connection with the retailer API to select which products should be returned by the data feed.
- Normalization: map the raw data in the retailer data feed to the definitions of the data standard. Data rules will need to be applied to common factor MPN, Brand, and product attributes.
- Aggregation: combine product specifications and prices (Min, Max, Mean, Median, and Standard Deviation of daily offers) from multiple retailer feeds to create and maintain a single, unique product record in the framework.
- Matching: update offers and product specifications on already existing products based on MPN or GTIN. Matching MPNs requires logic to strip extraneous characters and process the many wildcards present in certification records.

Data rules

Rules can be defined per retailer API to control for the variation in data quality coming from online data sources. The power of this data framework is that rules can be configured to reject products based on category attributes, using logical operators such as any, in, not, >, <, >=, <=, and =.

Examples would be: TV Screen Technology in “LCD, LED” or Screen Size > “15 inches” or for Room AC Volume Capacity <= “14 kW”. This ensures only data of the highest quality is captured into the framework. Additionally, it will be necessary to rewrite attribute names and values to normalize them across data sources and markets.

Certification Data Sets

Government certification/rating data will be utilized to capture products’ energy efficiency information. This data will be imported into the framework as a Comma-separated Value (CSV) file. The framework will then match each record’s MPN to an existing product in the database following the methodology below:

- Data set parsing: Certification data sets are uploaded in CSV format to add energy efficiency related attributes to product records.
- Matching: Capture the associated energy efficiency data such as energy consumption, certification level, certifying authority, registration date, etc. on already existing products based on a matched MPN or GTIN code.

If an MPN match is not successful there is also the capability to capture the certification record directly into the database. This will cover the use case whereby certification data sets contain historical products which are not currently available on the market.

2.6. Mapping Products Across Markets

As many manufacturers sell the same products across many markets using different MPNs and GTINs, there is a need to be able to link comparable products. The data framework includes a reference that links an MPN and/or GTIN from one market to another. The power in capturing product attributes in a standard way is to enable automated cross-market mapping.

By using logical rules to compare MPNs and key product attributes such as a product’s size, capacity, or energy consumption, the framework could facilitate identification of potential matches. As testing procedures may differ across markets, the challenge will be to identify which conversion factors and thresholds to apply. With the framework linking the test method with each product’s energy certification record, it would be possible to compare differences in the actual test procedure conditions (such as AC room temperature or TV viewing mode) between comparable products. Further analysis by all countries planning to participate in the data standard would be required to identify appropriate conversion factors and thresholds.

A good example would be for Samsung TVs across the US, Europe, South Korea, and Australia. Samsung TVs: UN40EH5000F (US), UE40EH5000 (Europe), and UA40EH5006M (Australia). Notice that the first two letters of the MPN define the market: UN for the US or South Korea, UE for Europe, or UA for Australia. This is the most basic way of identifying comparable products but does not guarantee success.

The next step would be to look at attributes such as Screen Size and Annual Energy Consumption. Using logical rules to first convert these attributes to a common unit of measurement, it will be possible to apply thresholds based on the underlying testing procedures to have the framework automate the identification of potential matches across markets. By continually fine-tuning the attribute conversion and threshold algorithms, the framework can significantly cut down on the amount of manual work required to clearly establish a set of like products across markets in each category.

3. Benefits of a Data Standard

A data standard accomplishes the following primary goal – improving access to data about consumer electronics and home appliances products' availability, pricing, and performance.

3.1. Existing Data

Currently, much of the data to feed into the proposed standard is not provided in a consistent format. For example, currently 26 countries have some type of minimum performance standard or energy performance labeling program.[4] Several of these have multiple programs, and may have different government or non-governmental agencies responsible for administering the program.

Each agency maintains their own qualification system, verifying that products comply with the requirements of their program. Often, these agencies publish lists of qualified products. For instance, the US ENERGY STAR program publishes a list of qualified products on their website.[5] This list contains 37 attributes about each product, such as manufacturer, manufacturer's product number, energy rating, size, and ENERGY STAR model identification number. Meanwhile, the Australian government collects similar information for its categorical labeling program, including 17 fields. Aligning these data formats to make reasonable comparisons across economies requires working directly with the governments that collect this data, as IEA 4E does in its mapping and benchmarking studies.

However, this certification data is further limited in that it doesn't necessarily represent the range of products available in a market, and it is not connected to price information. For instance, data from an endorsement label naturally represents the higher performing products on the market; it would not be possible to use this data to illustrate trends in efficiency of products in that market. However, each day vendors of this equipment are offering this equipment for sale – with associated identifying information such as manufacturer part number/model number (MPN), global trade identification number (GTIN) and manufacturer. By collecting these offers, we can know what fraction of the market is represented by the high performing products and what fraction of products do not have energy information available. When these products are available for sale, these products also have price information. By matching the offers for products at a given price with the energy rating provided by the rating agency, we can estimate average incremental cost for increased efficiency.

3.2. Uses

While a snapshot summary of most of this information can be done with existing tools, it requires significant undertaking on the part of the government or organization doing the research. In many cases, governments must purchase data or do their own research; the high cost of this puts it out of the reach of many organizations and often means that potential uses of the data are not cost effective. A data standard lowers the incremental cost of implementing any particular use by reducing the amount of work needed to reformat and clean the data sources.

Importantly, a data standard also opens up the possibility for continuous, real-time monitoring. Under the conventional approaches, the manual effort involved in collecting and aligning data sources means that information may lag by months or years, and only be available publicly in aggregate summary reports. While with the standard it make take effort to build an initial platform for viewing information, summaries can be updated on demand when source data is updated.

By developing a data standard, this data could be used to feed any number of applications or resources, limited only by what people are willing to design and create. We propose some potential applications of this data that could be developed.

Informing policy

Currently, it is an expensive process to collect data on market status and the availability of products. Most energy performance standards and labeling programs use cost-effectiveness as a test for setting improved target levels. This data standard could enable real-time monitoring of efficiency distribution within a market or region and changes in price among products of different efficiencies. Lowered cost of this process by automating the data collection can put this type of data collection into the reach of some governments that currently can't afford to do thorough market evaluation, and can shorten the revision process for those that already do this.

Cross-market advocacy

Currently, mapping and benchmarking studies by organizations like IEA 4E provide a way for countries to compare the performance of products in their markets. However, these are limited in how frequently they can be updated and how many products can be done. Implementation of a data standard would allow richer data to inform studies such as these, as well as broader product coverage.

Comparison of test methods

In many cases, products are available across markets and are tested to different standards. However, because of variations in test methods, direct comparison of the results is not possible – it is comparing apples to oranges. By using the data standard to identify the same product sold in multiple markets, conversion factors can be estimated.

Consumer mobile applications

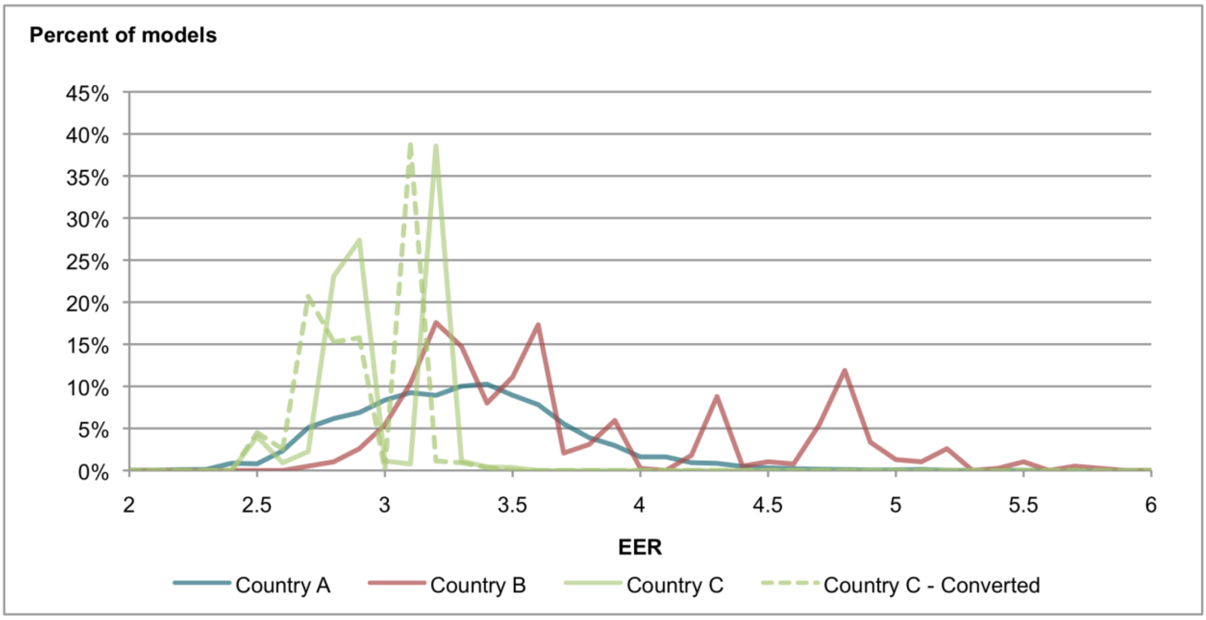
Currently, consumers must rely on energy efficiency information that is presented via various types of labeling schemes – usually showing the relative efficiency of a product and an estimated annual energy cost based on average utility rates and usage profiles (i.e. hours of TV watched per day). The data standard could enable developers to build a mobile application that allows consumers to scan a product's bar code to instantly compare personalized energy cost across all products of a specific class. The application could then recommend more efficient products within a specific price range that are available to purchase at local retailers within the consumer's local area. By also including the savings available from retailer incentives and utility rebates, it could incentivize consumers to purchase more energy efficient appliances.

4. Example Application

4.1. Efficiency Distribution Across Markets

As part of the development process, we collected sample data sets of room air conditioner performance from several countries. While this is the most basic comparison available, it does illustrate the first possible level of comparison. With the implementation of a data standard, this information could be made available via web portal that is up-to-date with current product information, along with data from additional countries.

Figure 2 – Distribution of Room AC EER



In this example, Country A and Country B follow the same methodology for calculating the energy efficiency ratio (EER). However, Country C uses a different methodology. Previous research assessed the differences in test procedures and demonstrated that the ISO 5151 test conditions could be estimated by dividing the NAFTA test condition EER used in Country C by 1.032. This conversion factor has been applied to the dotted green line in Figure 2. While this conversion approximation is available for EER, many other products do not have such conversions available. Applying analysis of the same products across markets, as described above, could be used to obtain additional conversions; building the test method and conversion factors into the data standards allows for improved comparison in product availability. [6] [7]

4.2. Price-Efficiency Trend Across Markets

A key additional benefit to the data framework is the ability to compare price to efficiency across markets. In the chart below, we show an illustrative example using real data to compare the average EER (in Watts Output/Watts Input), which has been normalized to W/W, and retail price level in US dollars for Room ACs across three different markets. This type of analysis could be automatically generated based on any interval (i.e. daily, weekly, monthly, quarterly) and using any price bucket (i.e. specific dollar amounts as shown below or more general divisions such as low, medium, or high). In addition, it could be filtered by size to look at the price-efficiency relationship for Room ACs of a specific cooling capacity.

Figure 3: Price-efficiency Comparison of Room ACs

5. Conclusion

This paper has presented the first steps of an attempt to develop the framework of an international consumer electronics and home appliances database and demonstrate some of its most important applications. The next stage of development will rely heavily on input from stakeholders within the SEAD initiative and elsewhere, to optimize and populate the database. Establishment of a full set of use cases will drive database design. In addition, the population of the database is in early stages. A major test of the data standard and algorithms will be its ability to associate products for offer in online shopping websites with models listed in certification database. The intended result of this project is a well-populated database that allows access to both efficiency and price data for a wide range of uses and end users.

An equally important outcome of the project will be the establishment of an international data standard for appliances. The natural follow-up to this outcome is to seek wide diffusion and stakeholder input, with the ultimate goal of seeking adherence to the standard from as many countries as possible. As argued above, the establishment and adoption of such a standard would yield rich benefits to policymakers, consumers and researchers concerned with consumer electronics and home appliances energy efficiency.

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The SEAD Global Efficiency Medal Competition: Accelerating Market Transformation for Efficient Televisions

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Abstract

The Global Efficiency Medal competition, a cornerstone activity of the Super-efficient Equipment and Appliance Deployment (SEAD) Initiative, is an awards program that encourages the production and sale of super-efficient products. SEAD is a voluntary multinational government collaboration of the Clean Energy Ministerial (CEM). This winner-takes-all competition recognizes products with the best energy efficiency, guides early adopter purchasers towards the most efficient product choices and demonstrates the levels of energy efficiency achievable by commercially available and emerging technologies. The first Global Efficiency Medals were awarded to the most energy-efficient flat panel televisions; an iconic consumer purchase.

SEAD Global Efficiency Medals were awarded to televisions that have proven to be substantially more energy efficient than comparable models available at the time of the competition (applications closed in the end of May 2012). The award-winning TVs consume between 33 to 44 percent less energy per

unit of screen area than comparable LED-backlit LCD televisions sold in each regional market and 50 to 60 percent less energy than CCFL-backlit LCD TVs.

Prior to the launch of this competition, SEAD conducted an unprecedented international round-robin test (RRT) to qualify TV test laboratories to support verification testing for SEAD awards. The RRT resulted in increased test laboratory capacity and expertise around the world and ensured that the test results from participating regional test laboratories could be compared in a fair and transparent fashion.

This paper highlights a range of benefits resulting from this first SEAD awards competition and encourages further investigation of the awards concept as a means to promote energy efficiency in other equipment types.

Competition Objectives

The SEAD awards program is part of a suite of policy interventions by governments designed to drive markets towards greater efficiency in electrical end-use equipment. The Super-efficient Equipment and Appliance Deployment (SEAD) Global Efficiency Medal competition recognizes products with the best energy efficiency performance, subject to certain quality constraints, in different regions as well as globally. This program complements existing standards and labeling programs in promoting energy efficiency.

The primary goal of the competition is to maximize energy savings by increasing the market share of efficient products. It also aims to spur innovation among manufacturers and foster international government collaboration to strengthen the technical foundation of efficiency policies for globally traded products. The competition process supports the harmonization of test procedures, the building of testing capabilities and the provision of internationally-comparable and transparent test results. The SEAD awards program is provides insights into market dynamics, stakeholder positions, potential market interventions, and gaps in the supporting policy environment for the product in question.

Competition Design and Features

The SEAD Global Efficiency Medal competition for flat-panel display televisions was launched at the International Consumer Electronics Show in Las Vegas, Nevada, USA in January 2012. Between August and October 2012, SEAD awarded Medals to Samsung and LG for producing the most energy efficient flat panel display televisions (FPD TVs) in the world. A global awards ceremony was held at the Clean Energy Ministerial in New Delhi on 17 April 2013. The awards are a pure recognition prize and do not involve a financial component.

TVs consume more than 3%-4% of global residential electricity consumption. Relative to a baseline prevalent in the market today, there is an energy efficiency improvement potential of up to 35% with more efficient technologies [11]. Based on technology market shares and specific technology efficiency forecasts, an average improvement of 10% is in energy efficiency expected over the business-as-usual forecasts as of 2012. The choice of TVs as the product category for the first round of the competition was driven by the significant energy savings potential and efficiency improvement potential indicated by the above analysis. Within the broader television category, the choice of flat-panel televisions was based on the trend of increasing global market share. In addition, the existence of a well-established, accepted international test method (IEC 62087) and the ability to differentiate TV models by their energy efficiency reinforced this selection. Finally, the relative homogeneity of the global market and market dominance by a few manufacturers contributed to the feasibility of launching a global competition and successfully promoting it to manufacturers.

The first SEAD Global Efficiency Medal competition aimed to encourage the production and sale of super-efficient TVs in three different size categories (small, medium and large as described in Table 1) and four geographical regions (Australia, Europe, India, and North America). Size categories were determined through a market analysis and are consistent with natural segmentations found in these markets. TV screen technologies sold in different regions of the world are very similar, as TV manufacturing is highly aggregated. The four award regions of the SEAD TV Awards account for more than 40 percent of the global TV market. An award ceremony to announce the European regional winners was held at the Internationale Funkausstellung (IFA) Fair on August 31, 2013 in Berlin. The global awards also recognized an overall winner for each size category, as well as the most efficient emerging technology product.

Table 1. Size Categories for Commercially Available Products

	Small	Medium	Large
Viewable Screen Area	Less than 2400 cm^2 (372 in^2)	2401 cm^2 (372 in^2) to 4800 cm^2 (744 in^2)	4801 cm^2 (744 in^2) to 6890 cm^2 (1068 in^2)
Nominal Diagonal Screen Size	Less than 29 in	29 in to less than 42 in	42 in to 50 in*

Note: TVs with screen larger than 6890 cm^2 (equivalent to 50 inches in diagonal) were eligible for this competition, but a value of 6890cm^2 was used as the screen area in the efficiency calculation (on-mode power/min{viewable screen area, 6890}) for these products.

Winning TVs were selected based on energy efficiency performance, which was evaluated as on-mode power consumption (expressed in Watts) normalized by screen area (expressed in square centimeters), using the IEC 62087: 2011 test procedure. Efficiency was evaluated based on product performance with "out-of-box" settings, and products were required to have a default luminance setting that was 65% of the maximum luminance (aligned with US EPA ENERGY STAR requirements). These requirements were aimed at ensuring that winning products delivered good picture quality and that test results were representative of real-world consumption, since most consumers use their TV's default settings. Additionally, products were required to have a maximum standby power consumption of 0.5W.

A note on the automatic brightness control (ABC) feature: According to the IEC 62087 test procedure, on-mode power consumption is measured with ABC disabled if the feature exists. If the ABC feature cannot be disabled, then measurements are performed with the light shone directly into the television's ambient light sensor at a level of 300 lux or greater, effectively disabling the ABC feature. The competition adopted the same approach to ABC.

The SEAD competition further established minimum sales requirements as a condition of entry to ensure market access of winning products. For the Commercially Available Technology product sub-category, applicants were required to have plans to sell at least a minimum number of units of a product model in the region of nomination as specified below.

Region	**Minimum Sales Threshold Units**
Australia	5,000
Europe	10,000 in one country or 50,000 units across all EU27 and EFTA-countries
India	5000
North America	50,000

The sales threshold was intended to ensure that award-winning TVs have a significant footprint in terms of market share, in order to maximize potential energy savings. For the Emerging Technology product sub-category, applicants were required to have plans for mass production of nominated products within two years of the end of the competition.

The competition identifies the most efficient products based on manufacturers' nominations, requiring active participation by the manufacturers, rather than awarding products based on publicly available data. The active approach was adopted, to expose interest from the manufacturers in producing more efficient products and spur innovation to compete and win the competition. Manufacturers entered the competition by submitting nominations forms with details about their products, including their on-mode energy usage. The Awards Administrator then identified presumptive wining products based on manufacturers' energy efficiency performance claims. Manufacturers were required to provide serial numbers for 50 products from different retail or warehouse locations from which the Awards Administrator randomly selected 2 products for verification testing. The tested products were required demonstrate an energy efficiency performance within a margin of 2 percent of the manufacturer's claims. Models that exceeded the 2 percent margin requirement during verification testing would be disqualified and the Awards Administrator would request test samples for the TV model with the next best energy efficiency performance claim for verification testing. Testing costs were borne by the SEAD governments of the respective Awards region while manufacturers were responsible for paying the shipping costs to send test samples to the laboratories.

A detailed description of the design of the competition can be found in a paper published in the conference proceedings of the 2013 European Council for an Energy Efficient Economy (ECEEE) Summer Study [10].

Competition Results

SEAD Global Efficiency Medals in the Commercially Available Technology category were awarded to the most energy efficient TVs in each of four award regions, as specified in Table 2. All award-winning models are light emitting diode (LED) backlit liquid crystal display (LCD) TVs.

Within each size category, winning products in each region were similar models from a single manufacturer, with minor technology differences to comply with regional regulations. This is reflective of the global homogeneity of the TV market and the market aggregation around a few manufacturers. The standby power of these models are well below the competition limit of 0.5W, following the global trends of sharply dropping standby power consumption driven by regulation.

Another interesting observation is that the large size winners consume less power and have lower luminance than the medium size winners. Since larger TVs typically consume more power, this demonstrates the commercial viability of technology that can significantly reduce the power consumption of TVs.

Table 2. Award-winning Models in Commercially Available Technology Category

	Size category	Australia	Europe	India	North America
Small	Model	Samsung UA26EH4000M	Samsung UE26EH4000W	Samsung UA26EH4000R	Samsung UN26EH4000F*
	On Mode Power (W)	24.4	24.9	24.9	22
	Viewable Screen Area (cm2)	1863.83	1863.83	1863.83	1863.83
	Standby Power (W)	0.15	0.13	0.13	0.13
	Max. Luminance (cd/m2)	220	260	240	240
Medium	Model	Samsung UA40EH5306M	Samsung UE40EH5000W*	Samsung UA40EH5330R	Samsung UN40EH5000F*
	On Mode Power (W)	47.4	44	47.4	44
	Viewable Screen Area (cm2)	4411.62	4411.62	4411.62	4411.62
	Standby Power (W)	0.15	0.17	0.15	0.17
	Max. Luminance	240	280	290	240

	(cd/m2)				
Large	Model	LG 47LM6700	LG 47LM670S*	LG 47LM6700	LG 47LM6700
	On Mode Power (W)	43.4	43,1	43.4	44.5
	Viewable Screen Area (cm2)	6080.6	6080.6	6080.6	6080.6
	Standby Power (W)	0.2	0.2	0.2	0.12
	Max. Luminance (cd/m2)	160	160	147	159

* International Winners
Note: More details are available at http://www.superefficient.org/TVawards

The SEAD Global Efficiency Medal in the Emerging Technology category was awarded to an LG 47-inch LED backlit LCD prototype TV that used an advanced optical film and back-light dimming technology. Per the competition rules and eligibility criteria, the Emerging Technology winning TV will be commercially available within 2 years of winning the SEAD Global Efficiency Medal.

Competition Outcomes

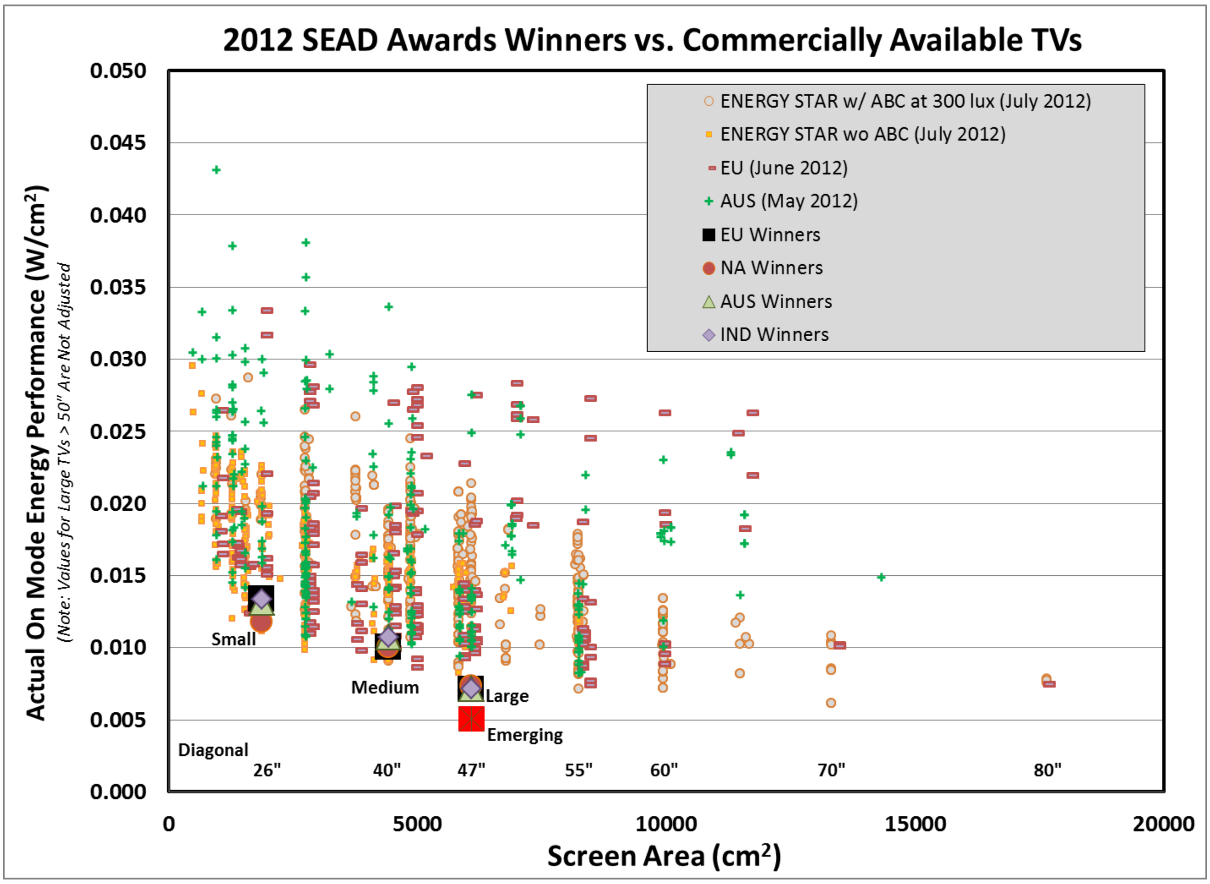
The first round of the SEAD Global Efficiency Medal competition provided many new insights into the global television market and demonstrated the potential for greater energy savings through increased product efficiency. This section provides an overview of the major findings that resulted from this competition.

1. Award-winning TVs are up to 71% more efficient than commercially available TVs, demonstrating significant efficiency improvement potential in flat-panel TVs

The energy efficiency performance of SEAD award-winning TVs was compared with TVs registered to regional databases in 2012. The dataset includes only TVs with standby power consumption less than 0.5 W and the luminance ratio between default home mode and brightest picture mode greater than 65 percent. [1], [4], [5] All TVs in the database were considered to be commercially available and weighted equally since sales weighted data was not available at the time. For North America, the dataset was taken from the U.S. EPA ENERGY STAR database and for Australia, the source of the dataset is the Australian Energy Rating. The majority of TV models compared with the European winning models are from the Intertek database, which can be regarded as representative of TVs sold in Europe. (Country-specific changes from basic models are made mostly in tuners.)

The performance of the award-winning TVs is shown in comparison to the other TVs in the different regional databases in Figure 1. The figure compares against two different U.S. EPA ENERGY STAR datasets. Since the U.S. EPA ENERGY STAR Version 5 on-mode power calculation is weighted by ABC for ABC-enabled TVs, award results are compared to on-mode power consumption of ABC-enabled U.S. EPA ENERGY STAR qualified TVs at high ambient lighting conditions (300 lux) and TVs without ABC. [1]

[1] It is also important to note that on-mode power with ABC at 300 lux is not necessarily the same as on-mode power with ABC deactivated.



Note: AUS (Australia), EU (European Union), IND (India), NA (North America), ABC (Automatic Brightness Control)

Figure 1. On-mode power performance (W/cm^2) –SEAD TV Awards Winners vs. Commercially Available TVs

Figure 1 shows that the award-winning models in the Commercially Available Technology category can be regarded as the most efficient products in the regional markets in most cases. However due to voluntary nature of participation, it is possible that the most efficient products were not nominated for this competition. It is also possible that the most efficient models do not meet the sales criteria stipulated by the competition. A more detailed comparison to the regional labels is available in [12].

The efficiency of award-winning models compared to the average efficiency among commercially available TVs in the different regions is summarized in Figure 2. “Conventional TVs” denote Cold Cathode Fluorescent Lamp (CCFL) backlit LCD TVs and “Comparable TVs” denote Light Emitting Diode (LED) backlit LCD TVs. The winners were at least 20% and as much as 71% more efficient than the average TV in the datasets. While the comparison was made to the average performance of the TVs in the database, the median performance was very close to the average.

The international award-winning model for the Emerging Technology category is approximately 30% more efficient than the winners of the large-size Commercially Available Technology category and approximately 59% more efficient than the most efficient models available in the market. This demonstrates that there is significant potential to improve the energy performance of TVs.

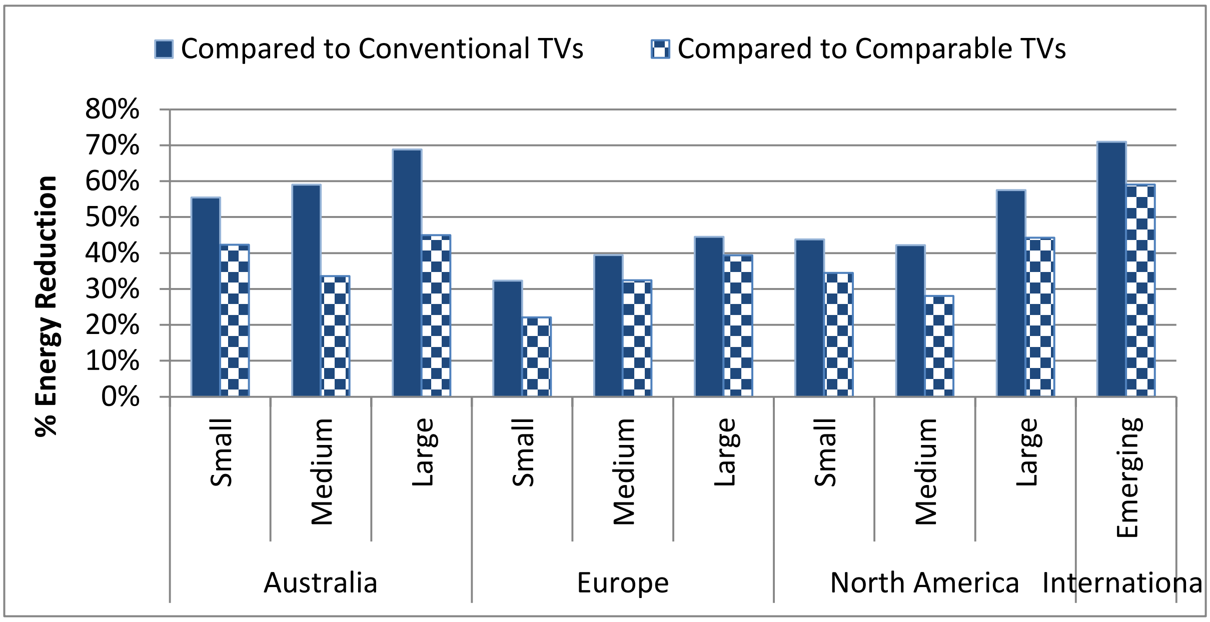


Figure 2. Comparison of Award-Winning Models vs. Commercially Available TVs

2. The SEAD Global Efficiency Medal spurs manufacturers to make ongoing changes in efficiency improvement

The regional award-winning models for the Commercially Available Technology category were already registered to the corresponding regional energy efficiency database, such as the U.S. EPA ENERGY STAR database. That is, these models were not new at the time of nomination; rather the models were a part of the manufacturers' existing product line. However, the on-mode power consumption values registered in early 2012 in the U.S. EPA ENERGY STAR database are higher than those claimed for the SEAD TV Awards.

Typically, manufacturers take into account a margin-of-error when reporting on-mode power consumption of their products to the regional databases. The volatile nature of television markets suggests that on-mode power consumption can be expected to decrease throughout the production year as manufacturers make running changes[2]. However, the 30 percent reduction in the energy use of the large size winner is well beyond the running changes typically achieved through the year. It is likely that the manufacturer made significant improvements to compete in and win this competition.

This improvement is an indication that the SEAD Global Efficiency Medal competition can spur innovation among manufacturers to improve the efficiency of their products. In fact, one of the winning manufacturers reported that they examined the product efficiency of their entire product line as a result of this competition.

3. Award-winning TVs demonstrate significant global energy savings potential

In our analysis, we estimate that if all the TVs sold were as efficient as the SEAD award-winning models, more than 84 billion kilowatt-hours (or 84 terawatt-hours [TWh]) of electricity would be saved worldwide in the year 2020 [12]. Table 3 provides the estimated savings by region.

If all new TVs (with the exception of OLED TVs) expected to be sold globally from 2013 to 2020 meet the efficiency levels that award-winning models for the Commercially Available Technology category have achieved, compared to the scenario of all new TVs with *no further efficiency improvement* within each screen technology from 2013 onward, it would provide annual savings in 2020 as follows:

- 2.9 TWh in Australia (equivalent to the national annual electricity use of Botswana [6])
- 17.2 TWh in Europe (equivalent to the national annual electricity use of Croatia [6])
- 5.4 TWh in India (equivalent to the national annual electricity use of Bolivia)

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[2] A generally accepted industry term denoting "ongoing design changes made throughout the year"

- 18.6 TWh in North America (equivalent to the national annual electricity use of Nigeria [6])
- 84.6 TWh, equivalent to 28 medium size coal-fired power plants with 500 megawatts capacity, or taking nearly 12.3 million cars off the road for a full year [9], in all regions (more than the combined annual national electricity use of Denmark and New Zealand [6]).

Table 3. Regional and Global Savings Potential for Efficiency Improvement in SEAD TV Awards

	Annual Savings (TWh)		Cumulative Savings (TWh)	
	in 2015	in 2020	2013-2015	2013-2020
Australia	1.2	2.9	2.5	13.7
India	2.3	5.4	4.6	25.9
Europe	7.0	17.2	14.0	81.1
North America	8.0	18.8	15.6	88.7
Global	34.8	84.6	69.8	399.6

If all new large TVs (screen size equal to or larger than 42 inches) expected to be sold globally from 2013 to 2020 meet the efficiency level that the award-winning model for the Emerging Technology category has achieved, it would provide additional annual savings in 2020 of approximately 12 TWh for all regions. This is the equivalent to 28 medium size coal-fired power plants with 500 megawatts capacity[3], or taking nearly 12.3 million U.S. cars off the road for a full year [9].

4. SEAD Award-winning TVs demonstrate that energy efficient products can be cost effective

For the U.S. market, Commercially Available Technology winners in the small and medium size categories are entry-level models and that are less expensive than comparable TVs (see Table 4), which suggests that consumers can reap electricity cost savings without incurring an additional first cost for efficient technology. This demonstrates that energy efficiency can come at cost effective prices. A type of LED-direct[4] backlit LCD TVs, often referred to in industry parlance as “low-cost LED-direct backlighting” or “emerging market TVs”, employ about half of the LEDs used in typical LED backlights, and use lower-cost optical components in the backlight system [13], [14], resulting in overall lower cost TVs for the same picture quality.

It is also possible to intelligently decrease the maximum luminance level and color-reproduction capability with material-based and algorithmic improvement and without sacrificing picture quality. Lower luminance allows manufacturers to use fewer LED lamps as well as low-voltage driven electronic parts in the circuitry [11].

Table 4. Market Prices and On-mode Power of the Regional Winners in North America and Typical TVs with Similar Technology

Regional Winners in North America			Typical TVs in the U.S. Market		
Model	Price[a]	On-mode Power Consumption	Model	Price[b]	Average On-mode Power Consumption[c]
Samsung UN26EH4000F	$260	22.0 W	26" LED-LCD 1366×768	$278	29.2 W
Samsung UN40EH5000F	$548	44.1 W	40" LED-LCD 1920×1080	$566	64.9 W
LG 47LM6700 (3D enabled)	$919	44.5 W	47" LED-LCD 1920×1080	$845 (3D)	92.2 W

[a] www.amazon.com, www.alltimetvs.com (lowest price, as of Sep 2012)
[b] Average market price as of Q3 2012 projected by DisplaySearch in Q4 2011 [2]
[c] Average on-mode power consumption of U.S. EPA ENERGY STAR qualified TVs in the given category. This data is measured in the same manner as specified by the competition.

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[3] In rough back-of-the-envelope calculations, if an efficiency technology or policy would save 3 TWh per year, it saves one 500 MW coal plant operating at 70 percent capacity factor in that year, this unit of energy savings is called one Rosenfeld [7].

[4] “LED-direct” or “LED full-array” configuration means that the LEDs are uniformly arranged behind the entire LCD panel. Unlike LED-direct models, “LED-edge” or “Edge-lit” configuration means that all of the LEDs are mounted on sides (or edges) of the display.

On the other hand, the large size winner (LG 47LM6700) does not appear to be cheaper than a typical model of its size. Another way to look at cost effectiveness is the cost of conserved electricity (CCE)[5]. CCE is estimated by dividing the annualized incremental cost (IC) (i.e., incremental price) of the energy efficient model by annual energy savings due to that option. For this calculation, the comparable product category is defined by screen size, backlight type and 3D capability (i.e., 47-inch 3D-capable LED-LCD TV). The CCE for the product category is calculated using annualized IC for the product category and energy savings for the product category, as follows:

$$CCE = \frac{annualized\ IC}{energy\ savings} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

$$annualized\ IC = IC\left[\frac{discount\ rate}{1-(1+discount\ rate)^{-lifetime}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Energy\ Savings_i\left(\frac{kWh}{year}\right) = Power\ reduced\left(\frac{watts}{unit}\right) \times daily\ usage\left(\frac{hours}{day}\right) \times \frac{365\ days}{year} \times \frac{1\ kilowatts}{1000\ watts} \ldots\ldots (3)$$

, *lifetime*$_i$ is the TV economic lifetime[6], i.e. and *discount rate*[7] is the discount rate of the end user.

Given that on-mode power saved is 47.7 W and the incremental price is $74, compared to a typical model, the winner in the large size category (LG 47LM6700) has CCE with a range of $0.105/kWh and $0.178/kWh as described in Table 5.

Table 5. Cost of Conserved Electricity (CCE) for the Large Winner (LG 47LM6700)

USD/kWh		Economic Lifetime				
		6 years	7 years	8 years	9 years	10 years
Discount Rate	4%	0.162	0.142	0.126	0.114	0.105
	5%	0.167	0.147	0.132	0.120	0.110
	6%	0.173	0.152	0.139	0.125	0.115
	7%	0.178	0.158	0.142	0.130	0.121

The average electricity price of the U.S is $0.115/kWh. Thus, the CCE of the LG 47LM6700 model, with 3D capability and wireless network functions, is currently similar to or higher than the average residential electricity prices of many states in the U.S. (in some regions, average residential prices (tariffs) are lower than the marginal residential tariffs---the tariff for the last unit consumed which is equivalent to the reduction in consumer bill if one unit of electricity is saved.) The market price of 3D capable 47-inch LED-LCD TVs was projected to come down to about $560 by the end of 2015 [2]. Therefore, while the winning model in the large size category may not be cost effective today, it is likely to become cost effective in the future.

5. Several energy efficiency organizations support the competition and the SEAD award-winning TVs through promotional campaigns and financial incentives

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[5] CCE is a metric used to compare the cost of saving electricity to the cost of providing electricity to assess the desirability of energy efficiency measures. CCE is estimated by dividing the annualized incremental cost of the energy efficient model by annual energy savings.

[6] In the U.S., the average age of recently replaced TVs was about 8 years [3]. This analysis provides the CCE results in range of 6 to 10 years.

[7] Residential and commercial sectors may use various methods to finance the purchase of TVs. The U.S. Department of Energy (DOE), in a technical support document for the energy efficiency program for consumer products analyzed that the average discount rates are 4.8 percent for residential consumers and 6.2 percent for commercial sectors [8]. This analysis provides the CCE results in range of 4 to 7 percent.

SEAD promoted the winning televisions through media campaigns and partnerships with key organizations with synergistic goals for promoting energy efficiency. Partner organizations include the Alliance to Save Energy, Consortium for Energy Efficiency, Consumer Electronics Association, Efficiency Vermont, Enervee, EPEAT, New York State Energy Research and Development Authority (NYSERDA), and TopTen USA. These organizations supported SEAD by promoting the Global Efficiency Medal competition and the award-winning televisions to their consumer base.

SEAD promotional efforts resulted in:

- Features in prominent media outlets across the globe, including Reuters and the Wall Street Journal. The competition was also promoted through popular consumer blogs such as CNET, ClimateWire, Gizmag, and Sustainable Brands. Winner announcements also appeared on digital displays in Times Square in New York City.
- SEAD award-winning TVs being placed in the top tier incentive of Efficiency Vermont's three-tier incentive program directed at retailers. Efficiency Vermont is a non-profit organization that provides technical assistance and financial incentives to reduce energy costs.
- A social media campaign to give away 10 SEAD award-wining TVs. Mass Save, an energy efficiency program in the U.S. state of Massachusetts, partnered with Samsung to organize the give-away.The sweepstakes was promoted through radio and social media campaigns and increased awareness of Mass Save's energy efficiency programs.

6. The SEAD Global Efficiency Medal competition supports testing capacity building and test method harmonization

Reliable and comparable test results are essential to a global awards program's credibility. To this end, it is critical to ensure that laboratories responsible for performing verification tests have the necessary qualifications and capabilities, and that common test protocols are available for use.

This competition employed the IEC 62087:2011 test procedure, an internationally accepted test procedure for TVs and other video equipment, to verify manufacturers' energy efficiency claims. An international round-robin test (RRT) was conducted across the designated verification test laboratories in the different participating regions by shipping the same set of 6 TVs to each laboratory and testing them in an out-of-box condition as per IEC 62087. An expert witness was dispatched to each laboratory and charged with ensuring the consistency of testing across all test laboratories. The expert witness assessed test laboratory equipment and provided training to lab technicians to ensure that all test labs were qualified to conduct TV efficiency testing according to the IEC 62087:2011 procedure. As a result, two test laboratories in India have improved testing capabilities, which are now the only test labs in India capable of testing television efficiency using IEC test methods.

At the request of the Philippines Department of Energy, SEAD extended the RRT to include a recently built government TV test laboratory. SEAD identified necessary improvements to laboratory equipment and trained several staff technicians. As a result, the Philippines Department of Energy TV test laboratory is now comparable to other leading international TV test laboratories.

Lastly, SEAD collaborated with the China National Institute of Standardization (CNIS) to incorporate the international SEAD television RRT in CNIS's ongoing national television round robin testing. This allowed SEAD to further validate the international test procedure used for verification testing.

It also allowed Awards Administrator to identify international winners without having to test all of the regional winners in the same test laboratory.

7. Data from the SEAD TV awards competition informs standards and labeling processes

The competition influenced energy efficiency standards and labeling in three different countries/regions as described below.

- *Korea:* Based on the test results from the SEAD competition, the Republic of Korea revised its television efficiency standards. These new standards are expected to save 2.2 billion kWh annually in 2020. That's enough to offset the CO_2 emissions of over 320,000 U.S. cars for a year [9].

- *India:* As a result of participating in the SEAD competition, India's Bureau of Energy Efficiency:
    - Added LED-backlit LCD televisions to the top category of their 5-star energy label
    - Is adopting the latest version of the IEC 62087 international test procedure as a basis for their efficiency labeling program. This was supported by the improved test laboratories described above.
    - Is improving the 5-star energy label rating criteria for color televisions.

- *Europe:* The SEAD competition informed the European Commission's revision of the EcoDesign regulation for televisions.

8. The competition's success necessitates further analysis of awards program as a concept

Outcomes of this first competition will help policy makers:

- Determine if an awards program can be an effective market transformation mechanism to promote energy efficient products in other markets,
- Inform subsequent rounds of the competition for other award category productsm, and
- See how efficiency improvement of globally manufactured products can be effectively accelerated.

This first round of the SEAD Global Efficiency Medal competitions merits further analysis to carefully establish its impacts in the aspects described below.

- An increase in the sales of internationally or regionally recognized award-winning products is expected to reduce electricity consumption in newly sold TVs that would otherwise have been less efficient. To determine the impact of the sales of the award winning TVs, SEAD proposes to purchase sales data for these TVs and perform further analysis to determine the net impacts of this competition.
- All award-winning Commercially Available Technology models within each size category are very similar in product design across all 4 regions. Consequently, it would be interesting to determine whether the cost effectiveness results for the U.S. market are applicable to other countries.[8]

Acknowledgements

This paper is based on earlier work and analysis, *Assessment of SEAD Global Efficiency Medals for Televisions*, of Won Young Park at Lawrence Berkley National Laboratory, in Berkeley USA. The request for this work came from participating SEAD government.

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Game Consoles: Comparing International Policy Actions

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Abstract

Video game consoles have been identified for policy action in the European Union (EU), USA, Australia and New Zealand. Game consoles, such as the PS3, Xbox 360 and the Nintendo Wii U are increasingly being used for non-gaming functions, including media play and motion control of entertainment systems. In Europe, the Ecodesign Directive on Energy Related Products (ErP) Lot 3 Sound and Imaging Equipment Impact study report identified game consoles as using over 6,000 GWh pa of electricity in 2013. In Australia, game consoles are estimated to use 395 GWh pa in 2010, representing over 15% of the total energy consumption by devices associated with household home entertainment (other than TVs).

Game console energy efficiency has been the focus of several international policy initiatives, including the EU Ecodesign Directive, US Environmental Protection Agency (EPA) ENERGY STAR, E3 program in Australia and New Zealand and the Appliance Standards for California. The EU is currently conducting an impact study on policy options for game consoles, while the Australian government has been exploring voluntary agreements with the game console suppliers to improve the efficiency of their products. The USA EPA has also established an ENERGY STAR recognition scheme for video game consoles, and the California Energy Commission (CEC) requested proposals for consideration of new appliance energy efficiency standards in California in October 2012. These policy initiatives are under development, but most propose maximum power demand limits for game consoles in various modes. Game play modes have been specifically excluded from some policies/programs, but media play/streaming and navigation modes are included. Standby power and auto power-down requirements are also specified.

These policy initiatives aim to improve the energy efficiency of video game consoles using a variety of approaches, voluntary agreements, Minimum Energy Performance Standards (MEPS) or endorsement labeling. There have been some early moves by policy makers to harmonize the various policy requirements, and this paper explores, compares and contrasts the different policy frameworks. It may be possible to leverage the existing policy initiatives and create an internationally harmonized requirement, or at least partial overlap, as the game consoles are traded internationally, with little variation in product design between markets. There are however challenges to address, including the different video and game-play specifications between console suppliers, and models.

Introduction

Game consoles are consumer electronic devices that are optimized to play video games and deliver media entertainment in the home. There are currently three main suppliers of video game consoles internationally; Nintendo, Sony and Microsoft (although it is recognised that more manufacturers are entering the market). They sell current generation consoles (Xbox360, PS3 and until recently the Wii) and are transitioning to future generations of game consoles (the Wii-U was released in late 2012), the PS4 (planned for release late 2013) and Microsoft's next generation console the Xbox One (also planned for release late 2013). There is usually a period of 4 to 8 years between releases of different generations of game console. During this period iterations of the same game console model may be released, with the manufacturers generally modifying the circuitry components with the aim of decreasing the power demand and size (or both). During these iterations there is often no significant change to the basic architecture of the platform. The game console market is changing however, with new types of game consoles coming to market which threaten to disrupt the current status quo of the three main players. These new types of game consoles are likely to be either lower powered devices or higher powered devices which are more closely related to traditional gaming personal computers.

Over the last four years, game consoles have been promoted as devices which offer more than just game playing functionality. Additional features include multimedia capabilities, such as HD video play back (streaming, video on demand, DVD, BluRay), entertainment (news, chat, web access), on-line gaming, TV tuners (add-on to PS3), and motion user interfaces (Xbox Kinect, Sony Move, etc.). The range of services provided by the three major manufacturers is increasing and the future of gaming is certainly changing to the motion user interface, very high definition video (e.g. 4K) and probably 3D capabilities.

In Europe, the recently published Energy Related Products (ErP) Lot 3 Sound and Imaging Equipment *Impact Assessment Study For Sustainable Product Measures* report estimated that game consoles used 6000 GWh pa of electricity in 2013 [1]. In Australia game consoles were estimated to use 395 GWh pa in 2010, representing over 15% of the total energy consumption by devices associated with household home entertainment (other than TVs) [2].

Several international policy initiatives have begun to focus on the energy efficiency of game consoles. These initiatives include the EU Ecodesign Directive, US EPA ENERGY STAR, E3 program in Australia and New Zealand and the Appliance Standards for California. The EU has undertaken a comprehensive preparatory study on game consoles which sought to detail the current and future environmental impacts arising from these products as well as identify policy options that could help to reduce the future impacts [3]. Following the preparatory study, the EU launched an Impact Assessment which sought to quantify the energy savings that could be achieved through the introduction of different policy measures aimed at game consoles and updated some of the background technical data found in the earlier preparatory study. The Australian government has also been exploring policy measure options which tackle the energy efficiency of game consoles. The US EPA has developed an ENERGY STAR specification for game consoles in anticipation that manufacturers will strive for ENERGY STAR recognition. ENERGY STAR is not the only US based initiative aiming to improve the energy efficiency of game consoles as the CEC is also investigating the development of mandatory energy efficiency requirements for game consoles. Most of the policy measures appear to focus on maximum power demand requirements in non-game playing modes such as media playback, navigation and low power modes. Attention has not focused on game play modes due to the close correlation between game play functionality and power demand. These developments are described in the following sections.

Game console power demand and energy use

Comparison of power demand and modes of operation

The energy use of game consoles is a function of the power demand and usage time by mode. There are several different modes of operation found in game consoles but these may not be standard across all consoles. The main power modes found in game consoles can be seen in Table 1 (based on ENERGY STAR requirements [4]).

Table 1: Modes of operation

Mode	Description
Game Play	A game is actively loaded and running either with or without user input.
Game Play pause	A game otherwise being played is paused after receiving user input or an automatic signal
Media Play	The game console is providing video or audio playback
Video Stream Play	playing a video via a network connection
Optical Disk Play	playing a video via an optical disk
HDD Video Play	playing a video direct from an internal or external storage device
Audio Stream Play	playing audio via a network connection
Optical Disk Play	playing audio via an optical disk
HDD Audio Play	playing audio direct from an internal or external storage device
Navigation	Includes the screen(s) initially displayed for user navigation through the game console operating system (e.g. the home menu)
Network standby	A lower power mode where the game console maintains connectivity to at least one external network.
Standby/Off	The mode where the game console is plugged into a power source but is not providing any primary or secondary function and has no saved hardware state. The game console has no active network link although may be capable of charging devices in this mode

The current High Definition (HD) generation consoles have managed to reduced their overall power demand from over 180 W when first released in 2008 to around 60W to 90W now in game play mode. However, power scaling of internal components during media play back or navigation mode is minimal and so power demand remains relatively high. Microsoft and Sony have both engaged with policy makers and advocates to develop an Auto Power Down (APD) functionality that is progressively being applied to their current generation game consoles via a firmware update. The APD is planned to be set to 1 hour or less from the time of the last user interaction and after 4 hours or less of audio or video media playback (or 1 hour after video play has finished). These measures have improved the energy efficiency of game consoles however there are concerns that with increased media play and no power scaling, energy use will trend higher. Table 2 shows the power demand by mode of use, for the various game consoles in the market during 2012.

Table 2: Video Game Console Power Demand by Mode (Watts) 2012

Mode	MS Xbox 360 (W)	Sony PS3 (W)	Nintendo Wii (W)	Nintendo Wii U (W)
Off or Standby	0.67	0.05	10/0.8*	11.0/0.5*
Idle (UCI Home Screen)	76.9	67.6	13.0	32.0
Gameplay	81.3	76.6	14.4	35.0
Video Streaming	73.8	61.9	13.3	29.0
Video - DVD	58.9	73.5	n/a	Unknown

Source: EnergyConsult 2012 [2], and CEC for Wii U [5].
* Wii power use in standby mode WiiConnect24 enabled/disabled

Energy Consumption

The energy consumption of game consoles has been estimated in Australia to be 395 GWh pa in 2010, representing over 15% of the total energy consumption by devices associated with household home entertainment (other than TVs) [2]. The EU has estimated that game consoles used 6,000 GWh pa of electricity in 2013 [1]. Forecasts of energy consumption by game consoles are difficult to undertake, as assumptions need to be made regarding the sales, power and usage of future games console products, and these details are not released by the manufacturers before the launch of a product. However, in Australia, the EnergyConsult study has assumed that next generation game consoles will have power demand by mode and incremental reductions similar to current generation products as hardware is modified. APD was assumed to be implemented. Another key assumption of this study was that usage would remain at current levels (approximately 1 hour game play, 1 hour media play and navigation mode and 22 hours standby mode per day). The study forecast that energy use of game consoles will increase by 19% to 470 GWh pa in 2020.

Using this forecast model, updated scenarios have been provided with different usage and the power demand of the latest next generation game consoles. If usage increases along the trends shown in the Nielsen survey for 2012 [6], the average time spent playing games on consoles will decrease while the time spent streaming video, watching movies or other functions (music, internet browsing) will increase. Assuming that the game console manufacturers continue to improve the media capability and content of the next generation and current game consoles, a scenario was modelled with slowly increased usage (~ 3 mins per day per year increase in game play time and 9 mins per day per year increase in media play till 2020. Total game play = 1 hr 24 mins, total media play = 2 hrs 10 mins in 2020). This results in an increase of energy use by game consoles by 60% to 640 GWh pa in 2020 as shown in Figure 1 and demonstrates that the assumptions relating to usage are critical to estimating the overall impact of game consoles and energy use.

Similar proportional increases in total energy consumption have also been estimated in the EC Impact Assessment study [1]. Under the BAU scenario, energy consumption by Games Consoles is estimated to increase from 6,000 GWh pa in 2013 to 11,000 GWh pa in 2020, an increase of over 80%.

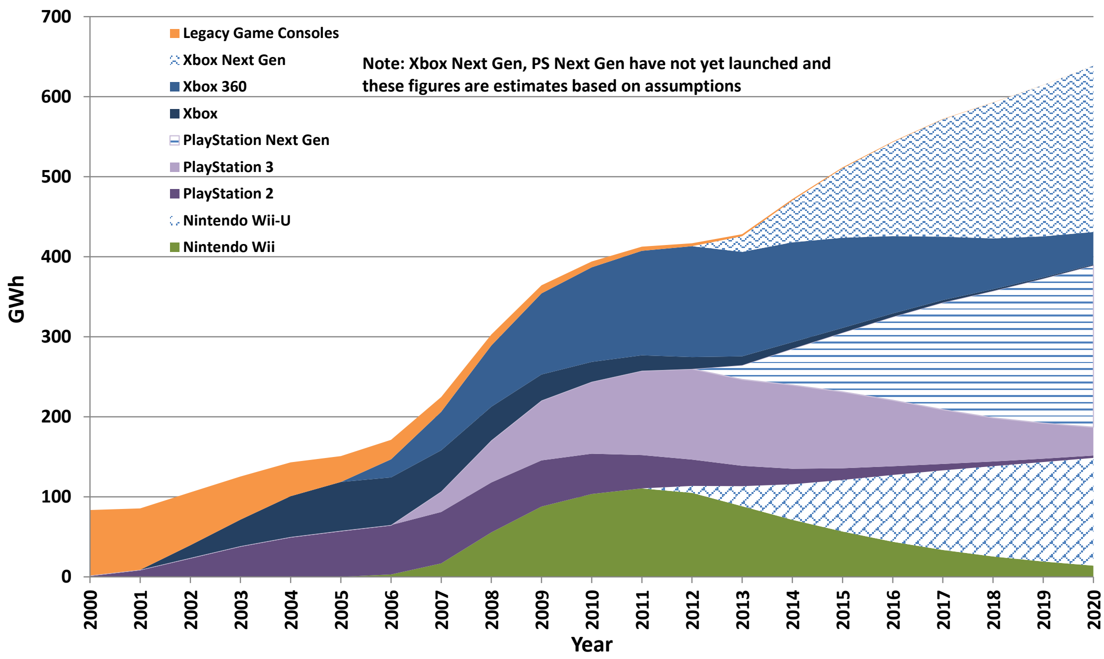

Figure 1: Forecast energy consumption of game consoles in Australia with increased usage.

Game console policy initiatives

Europe

The European Commission – as part of the Ecodesign Directive 2009/125/EC on Energy Related Products (ErP), is investigating possible policy approaches for 'sound and imaging equipment', of which game consoles are included. A preparatory study identified game consoles for action in December 2010, and the commission is undertaking an Impact Assessment Study [1] in 2013. This study, of which a draft consultants' report has already been published, investigates several policy approaches, including voluntary agreements and mandatory regulations. The main options considered, which offer greater potential energy savings that under the BAU scenario; are:

1. **Industry proposal for self-regulation/self-commitment**: with draft energy efficiency criteria. The feasibility of this proposal would depend on sufficiently stringent requirements that result in an improvement over the business-as- usual scenario and a clear commitment to future revisions as products evolve. Also, the effectiveness would require the participation of all 3 manufacturers (there is a risk that if just one manufacturer was to default then the failure rate would be 33.33%). An appropriate legal framework would be required for administrative aspects of the agreement (there is currently no clear legal commitment by the three manufacturers in the draft document).

2. **Mandatory Ecodesign requirements (regulation):** This option would involve setting mandatory maximum levels for the power demand of game consoles. The aim is to: (i) set limit values at a level providing the highest energy savings while ensuring no negative impact on product functionality and affordability, and (ii) specify implementation timing so that the cost-effective potential is realized as early as possible while ensuring that the industry has sufficient time to redesign the effected products.

3. **Mandatory energy labeling**: Energy labeling has advantages in terms of transparency, consumer information and consistency with approaches for other products. However this approach has significant issues that decrease effectiveness. There are only three main product types/models and product architectures vary widely between the three different products. This means considerable differences in functionality and power demand between each manufacturer's product may make application of an across-the-board categorization

unrepresentative. In addition, the level of energy efficiency exhibited by a game console is unlikely to be the most important purchasing criteria for most consumers. Despite these drawbacks, the EC considers that impacts may be estimated and are included in the Impact Assessment.

The potential for an international agreement on game console energy efficiency, (brokered by the Australian Department of Climate Change and Energy Efficiency (DCCEE) under the IEA banner within the 4E implementing Agreement) is under exploration. As an example, an international agreement could involve as a minimum the EC, the Australian DCCEE and the CEC. The chosen requirements could be the most robust of the requirements from the EC and Australian industry initiatives. There are advantages in this approach for manufacturers, as there will be less variation in requirements placed upon them among countries. There would need to be active input from the EC and other collaborating countries to ensure that the end agreement complied with the principles of effectiveness, efficiency and consistency. An Internationally recognized agreement was considered by the EC, but as discussions are at an early stage, the effectiveness of the proposal could not be evaluated. The EC Impact Assessment assumes the outcomes would be broadly comparable to either the industry proposal approach or the Mandatory Eco design option, depending on the requirements put forward.

Australia and New Zealand

The DCCEE have been investigating the potential for a voluntary agreement with the game consoles manufacturers since 2011. They received the industry proposal in August 2012 (which is the same as the European Commission received from industry [7]). A study by EnergyConsult recently reviewed the impact of game consoles energy use and efficiency opportunities and was prepared with input and suggestions from game console manufacturers (however they do not endorse the study). A voluntary agreement must demonstrate energy savings above the Business as Usual (BAU) for it to be considered acceptable by the Australian and New Zealand governments. The industry proposal does not appear to provide significant benefits compared to the BAU, and hence the DCCEE is now investigating other options, especially harmonization with similar regulatory approaches internationally.

USA

EPA Energy Star

The US EPA ENERGY STAR program has released their "Recognition Criteria for Game Consoles", which recognizes game consoles that meet the energy efficiency criteria, measured by the ENERGY STAR test method [4]. The EPA has proposed maximum power limits for three modes: Active Navigation Menu (40.0 W), Active Streaming Media (50.0 W), and Standby (0.5 W). Auto Power Down (APD) is also specified and activated by default. The game console must auto-power down to a Standby Mode within the period of user inactivity specified (1 hour for Active Game Play/Game Pause, Video Stream Pause or navigation Menu and 4 hours for Active Video Stream Play)

The EPA recognizes that consoles are increasingly providing non-gaming services, such as media play and could demand similar amounts of power as devices providing these same services (standard IP set-top boxes typically consume 10-20 W). These voluntary requirements are reflective of current and well-tested approaches used in related products and are intended to incentivize greater efficiencies in game consoles. The EPA will recognize manufacturers that take the steps to make energy efficiency a top priority for the design of their game consoles. Leadership is demonstrated by the companies who achieve these levels of performance. However, it is less clear if ENERGY STAR recognition will encourage purchasers to consider energy efficiency above other features of game consoles such as gaming functionality.

California Energy Commission (CEC)

The CEC requested proposals for consideration of new appliance energy efficiency standards in California in October 2012, and has prioritized game consoles for investigation in Phase 1 (2nd Qtr. 2012 to 2nd Qtr. 2013). The modes and levels proposed by the CEC are not yet published.

The CEC has received a proposal from the state Investor Owned Utilities (including Pacific Gas and Electric Company, Southern California Edison, Southern California Gas, San Diego Gas & Electric) for

Video Game Consoles. The proposal was prepared by the Natural Resources Defense Council (NRDC) [8] and proposes that California adopt a two-tier standard (2014 and 2016) for video game consoles, including auto-power down requirements and power limits in significant modes other than active gameplay. The proposed limits are shown in Table 3.

Table 3: Proposed Tier 1 and Tier 2 Measures by the NRDC for the CEC New Appliance Regulations

Function	**Tier 1 – Jan 2014**	**Tier 2 – Jan 2016**	**Rationale**
Auto Power Down (APD)	Enabled by default	Enabled by default	Savings estimate: 50% reduction in idle time.
Active Gameplay	N/A	N/A	No limit on active gaming for fairness with gaming PCs and in order not to impact performance.
Inactive - Gaming (Pause)	70 W	60 W	Console needs to scale power-down when not fully utilizing the capabilities of the device.
Navigation	70 W	60 W	Modest reductions from current levels, recognizing that this is a transitory mode with a limited impact on annual energy use.
Media (movies, music, internet)	50 W	25 W	Benchmarks: - Most efficient stand-alone Blu-Ray player: 9.9W - Wii movie streaming: 14 W
Other modes (internet browsing, photos, music, set-top etc.)	70 W	60 W	Same as Navigation. If any of the other modes emerge as one of the primary uses of consoles, specific limits would need to be set.
Standby/Off	0.5 W	0.5 W	Same as EU Ecodesign 1275/2008
Networked Standby	4.0 W	2.0 W	Same as proposed EU Ecodesign Lot 26, which have recently changed to 6W and 3W

In June 2013, the CEC issued a request for proposals from stakeholders in relation to the potential efficiency opportunities from Game Consoles. These stakeholder proposals will be considered by the CEC staff in formulating a staff report with draft proposed regulations. The staff report and draft regulations (if applicable) are likely to be published in the late 2013.

Comparison of policy initiatives

To contrast the approaches by these different regions/programs each of the following key factors has been compared:

- Policy Approach - mandatory, voluntary, endorsement,
- Metric for performance measure – power demand by mode or Typical Energy Consumption (TEC) or similar
- Modes of operation - game play, media play, standby, etc.
- Testing method
- Timeline
- Scope

Policy Approach

The policy approach to be used by each of the programs is yet to be determined; however a comparison is made in Table 4.

Table 4: Policy Approaches

Region/Program	Approach
Europe – Ecodesign Directive	**Not Decided**, voluntary agreement, mandatory labelling mandatory measures to be fully investigated
USA – ENERGY STAR	**Recognition** of those manufacturers that pledge to meet ENERGY STAR requirements
USA – CEC	**Not Decided**, but mandatory appears to be favored based on historical rules
Australia New Zealand	**Not Decided,** joining an international agreement is preferred

The USA ENERGY STAR program is currently the only formally announced policy measure on game consoles, and has opted for recognition of those game consoles that meet the published ENERGY STAR requirements. If a substantial economic region (such as the EU or California in the USA) implements a mandatory approach, this may become the de facto international standard as manufacturers will be unwilling to forgo such a market. The implementation of mandatory limits (such as MEPS) aims to prevent poorly performing products from entering the market. However as there are only three main consoles from the manufacturers currently being sold, a MEPS may prevent one or more manufacturers from offering their product. If this occurs, the overall efficiency may increase, however the reduction in product availability may have a detrimental effect on consumer choice. This may not occur, if all the suppliers meet the MEPS levels, but the risk is that manufacturers may choose not to enter a particular market if the product changes required to meet the MEPS are too costly or difficult to achieve over a short time frame. However, this potential negative aspect for MEPS can be offset by developing suitable mandatory levels which ensure energy efficiency without being too stringent as to remove products from the market place.

Metric for performance measure

The measurement metric that will be employed by most of the policy measures discussed above is yet to be defined. However the application of Maximum Power Limits (MPL) by mode appears to be the favoured choice rather than other approaches such as energy efficiency metrics. A comparison is made in Table 5.

Table 5: Metric for performance measure by Region

Region/Program	Approach
Europe – Ecodesign Directive	**Most likely approach**, Maximum Power Limit (MPL) by mode
USA – ENERGY STAR	**Decided,** Maximum Power by mode
USA – CEC	**Not Decided**, but Maximum Power Limit (MPL) by mode appears to be favored based on submissions to the 2012 Rulemaking
Australia New Zealand	**Not Decided,** joining an international agreement is preferred

A Maximum Power Limit would provide certainty to the manufacturers that the absolute maximum power demand in a certain mode is not to exceed a specific value. The verification is relatively simple and straightforward, with power measurements taken during each predefined mode of operation. A Typical/Total Energy/Electricity Consumption (TEC) metric for performance measurement takes the power demand of the devices in various modes and multiplies this by an assumed period of time to produce an energy consumption figure over a given period of time. A maximum TEC value is then set and the manufacturers are free to meet the TEC value by reducing the power demand in different modes in a flexible manner. While this approach provides some flexibility, the assumed time spent in each mode is often difficult to establish and varies by region and potentially by game console model. The TEC approach provides an incentive to manufacturers to minimize the energy consumption of products in all power modes while providing some flexibility on how much power may be used in each mode.

A major issue with any TEC approach is the need to define and consistently measure all the major power modes of game consoles and to identify suitable periods of time for each power mode. For example, one of the major modes that could potentially be included in any TEC approach is "game play". The game play mode is difficult to measure as there can be variation in user behavior, the performance specifications vary between game consoles and there are few games released for all three of the game consoles currently on the market. It has only been since late 2012 that all three game console suppliers have a HD console on the market and the features of future generation game consoles are not known until they are released. This makes direct comparisons of game play performance difficult to measure.

Modes of Operation and Maximum Power Limits (MPL)

Perhaps the most contentious issue for harmonization approaches for game console policy is the selection and definition of various modes that are included in the metric for measuring performance. Table 6 shows the various modes chosen or potentially proposed for the regional programs.

Table 6: Modes of Operation Considered and MPL where relevant

Mode/Feature	Europe – Ecodesign Directive(1)	USA – ENERGY STAR (2)	USA – CEC (3)	Industry Proposal (4)	Australia/ New Zealand
Timing (Tier 1/2)	2014/2017	2013	2014/2016	2013/2017	Joining an international agreement is the preferred option
Game Play	✗	✗	Not Decided	✗	
Game Play pause	✗	✗	70W/60W	✗	
Media Play MPL	70W/50W	50W	50W/25W	90W/70W	
Video Stream Play	✓	✓	✓	✓	
Optical Disk Play	✓	✓	✓	✓	
HDD Video Play	✓	✗	✓	✓	
Audio Stream Play	✓	✗	✓	✓	
Optical Disk Play	✓	✗	70W/60W	✓	
HDD Audio Play	✓	✗	70W/60W	✓	
Navigation	70W/50W	40W	70W/60W	90W/70W	
Standby	1W	0.5W	0.5W or 1W	0.5W or 1W	
Network standby	6W/3W	In future	4W/2W	4W/4W TBC	
Auto Power Down	✓ (1 hour)	✓ (1 hr, 4 hr media play	✓ (1 hr, 4 hr media play	✓ (1 hr, 4 hr media play	
Natural User Interface Additional Allowance	7W/5W	✗	Not yet considered	20W/15W	
Power Supply Efficiency	✓	✗	Not yet considered	✗	

Sources: (1) Europe – *Impact Assessment Study For Sustainable Product Measures – Lot 3 Sound And Imaging Equipment, 2013* see [1]. **Not Decided**
(2) USA – **ENERGY STAR** – Final Version 1.0 EPA Voluntary Criteria for Energy Efficient Game Consoles see [4]. **Decided**
(3) USA – CEC, Based on the submission by utilities PG&E, SCE, SoCalGas, SDG&E to the CEC see [8]. **Not Decided**
(4) *Energy Efficiency of Games Consoles* , by Sony, Microsoft and Nintendo, submission to Australia and Europe Commission see [7]. **Draft outline Proposal**

The coverage and MPLs described in Table 6 are not yet confirmed in the majority of regions, however early indications show that regional differences may exist if the preliminary proposals are adopted. Also, the ENERGY STAR requirements are not comparable to the MPLs for a regulatory program, as the ENERGY STAR requirements recognize the most efficient products in a category and are revised regularly to ensure they maintain this bias. There appears to be consistent consideration of the Standby Mode with all regional programs requiring that the European Commission Ecodesign regulations 1275/2008 [9] are met. Similarly, the proposed Network Standby limits are mostly similar to the Lot 26 draft amendment (27/07/2011) to the ErP standby regulation (EC) No 1275/2008. ENERGY STAR has noted they will adopt the outcome of this regulatory proposal in their future game console requirements.

The proposed MPLs for Media Play and Navigation mode range from 90W to 25W across the regions/programs. There are also substantial differences in the coverage of modes, with ENERGY

STAR not considering audio play and the other proposals including this mode. Other programs are also considering the addition of allowances for gesture and speech recognition Natural User Interface (NUI) functionality. The game console industry proposal has proposed the highest limits for most modes. Again, many of the programs have not yet officially proposed modes and MPLs and hence the final proposals may differ or converge.

Auto power-down is another area where all programs agree with the implementation of this feature, but differences may exist in the implementation. There are various discussions underway between program officers and the industry to determine the best way to implement APD without impacting on the user's operation of the game console or encouraging users to bypass the APD. These discussions center on the ways users can change the default settings (or accept the defaults on setting up the games console) and how accessories bundled with the console and using the console as a direct power source shall also power-down.

Scope

The scope of coverage of the various programs can also vary; with the ENERGY STAR program not applying to game consoles incapable of rendering HD (720p) video output via HDMI. The EU scheme will likely apply to '*Mains powered standalone devices providing video game playing as the primary function through an external screen'*, which includes all current generation consoles as well as future generation game consoles. There are no indications on the scope of coverage for the CEC appliance regulations at this time.

The definitions of Media Play are possibly another area where the scope of coverage could be important. In the industry proposal, Media play is playing of anything up to high definition (1080p), whereas the future generations of game consoles are likely to support 4K content or even higher definition content.

International Harmonization

These policy initiatives discussed earlier aim to improve the energy efficiency of video game consoles using a variety of approaches, voluntary agreements, MEPS or endorsement labeling. There have been some early moves by policy makers to harmonize the various policy requirements; however there are potentially major differences in the modes, scope and MPLs proposed in the various policy frameworks.

The most effective framework for international harmonization is still to be explored, with some proposals to the IEA 4E implementing agreement [10] considering game consoles as a separate work area. If the regional programs can cooperate to create an international framework for harmonization, there will be significant advantages, including:

- Supplier certainty – regardless of the nature of the policy initiative, suppliers will be able to produce and sell game consoles across regions without modification to their products.
- Greater negotiation power – the regional policy officials may be able to negotiate more effectively and enhance the efficiency outcomes when all regions agree on the same MPLs and modes.
- Lower policy development costs – if the policy initiatives are sharing common technical/market resources.

It may be possible to leverage the existing policy initiatives and create an internationally harmonized requirement, or at least partial overlap, as the game consoles are traded internationally with little variation in product design between markets. There are however challenges to address, including the different video and game play specifications between console suppliers and models. At the very least there seems to be potential for the harmonization of energy efficiency programs targeting game consoles in the following areas:

Standby and Network Standby Levels – all programs have initially proposed to harmonize with the European regulatory requirements of ErP.

Modes for MPLs – the majority of programs target media play and navigation. These are fairly easy to define and measure. The remaining issues to be harmonized are the media playback modes included and the MPLs specified. The largest area of contention will likely be the target values for MPLs. It should be possible for all regions to specify the same MPLs, taking into account the differences between programs targeting recognition and those regulating minimum performance standards.

Auto Power-Down – the requirements for APD are very similar between regions and the industry proposal (auto power-down after last user interaction of 4 hours for media play and 1 hour for all other modes). There are few potential small variations to finalize, including the default settings for disabling and setting up APD and including peripheral controllers/interfaces.

Timing – the programs have focused on two tiers – with levels for the Tier 1 in 2013 or 2014, and Tier 2 from 2016 to 2017. The timing appears to be very close to common dates for all initiatives, however these are not yet decided.

The major areas of difference will require further research and negotiation. These are likely to include:

- MPLs for Media Play and Navigation – agreement on the appropriate levels for regulatory programs will require significant cooperation between regions/programs.
- Game Play Pause – the inclusion of this mode is not supported by the manufacturers. The ENERGY STAR program focused on using APD to save energy when the user pauses the game rather than a MPL for this mode.
- Power Supply efficiency – it is argued by ENERGY STAR that a manufacturer should have the design freedom to meet the MPLs via whatever cost effective method is applicable to their console, rather than a prescriptive requirement on the power supply componentry.
- Allowances for NUI – the inclusion of various Gesture and Speech Recognition Natural User Interface (NUI) functionality will increase the power demand of game consoles, however further research is required to determine the appropriate levels/allowances.
- Charging peripherals – there is likely to be greater power use by consoles as controllers incorporate secondary screens (e.g., Wii U) and require these devices to be charged from the primary console. How APD is implemented without impeding the user experience will be essential to ensure that consoles power-down after the peripheral is charged.
- Network Standby Modes – the availability of network connected consoles will increase the importance of this mode and the impact of standby power in the overall console energy use. As network connections are prevalent now, the efficiency of how they are implemented will be highly important to the overall potential energy savings. If a product uses 8W when in a network connected mode, its overall energy use in this mode will be significantly higher than most current generations of game consoles. However, game consoles which provide more functionality in network standby mode, such as support for software updates, may allow for game consoles to spend more time in this mode than in on mode and therefore save energy overall.

These challenges are potentially addressable when local policy makers and technical experts engage with the manufacturers in a coordinated and resourced manner. Examples of other product groups that have led to generally agreed outcomes in recent times include MEPS for external power supplies and televisions. These two product groups include products that are generally manufactured in a single location but traded internationally. The coordinated test development and policy action led to the creation of international test methods and agreed performance levels across many jurisdictions. This same approach could be used for game consoles, especially as very few manufacturers need to be engaged.

Technical Challenges

There are a number of technical challenges to the development of policies that aim to reduce the energy use of game consoles. The key issue for game consoles is that power and functionality in some power modes is closely correlated (meaning reducing power may reduce functionality, especially in game play mode). Also, the functionality in one mode (e.g. game play) can influence power demand in another mode (e.g., media play back) because the commands are run through the same components. Some proponents suggest that separate components may be a way to reduce the power use (such as separate DVD player integrated into the game console), however separate components can't be easily used or their functionality updated via software updates. Perhaps a better approach is to use power scaling, where the power use is scaled down and up according the use/function of the device. The amount of power used by the current generation of consoles only decreases by 10% to 20% when playing a video or streaming media. Other media devices and PCs can reduce power demand significantly when lower levels of processing power are engaged.

Finally, the exact functionality of future products is often not known. This creates a situation where policy makers are unable to assess the impact on functionality from power demand limits placed on individual power modes and rely on the manufacturers to indicate what is possible. For example, the suppliers provided statements to the EPA Energy Star process [11] that *"neither the navigation nor the media streaming power caps suggested in Draft 3 are achievable, either by the present generation of game consoles or by employing the best scalable technology appropriate for any next generation console platform*". Nintendo released the Wii U a month later which easily achieved these requirements.

There are also difficulties in comparing game consoles with other products, such as gaming notebook PCs, which offer higher functionalities than current generation game consoles but use significantly less energy. To compare game console with gaming desktops, which may use more energy but provide a higher graphic functionality, is also difficult. Comparisons to gaming computers are difficult because these products provide significantly more functionality than most game consoles but may have very different energy use profiles such as significantly higher active mode power demands but lower idle mode power demands. Game consoles, on first release, may also offer significantly more functionality than an average gaming computer and so initially have higher power demands which are reduced overtime as more efficient components become available. However, the game console manufacturers have more control over the manufacturing and the software that is used on the devices compared to computers, which should enable greater system optimization. Other comparisons can involve comparing game consoles with stand-alone media/optical disc player/streaming devices, which use between 10W and 25W, compared to the Nintendo Wii U (32W) and current generation HD consoles (60W to 70W). These media playing devices have less functionality than game consoles.

Policy Challenges

There a number of policy challenges to the development of internationally harmonized energy performance goals for game consoles. These include:

- **Different timing** – various regional policy approaches are progressing at different rates, with some (e.g., ENERGY STAR) already announced. The EU is likely to announce their policy approach during 2013, while the CEC has just begun their appliance standards rulemaking. These different timings inhibit the development of coherent approaches because when government policy developments are progressing at different rates this creates multiple timings for implementation.
- **Different policy drivers** – some regional policy approaches are targeting voluntary or mandatory minimum energy performance standards while others are setting aspirational targets. These varied objectives create differences in the targeted levels for game console energy performance.
- **Different levels of ambition and political support** – the targeted power levels envisage an improvement over the BAU scenario. However, various regional jurisdictions have diverse levels of ambition in this regard and likewise different levels of support by the political leaders. Greater levels of ambition usually require high level support from leaders in political institutions as industry may lobby against implementing significant changes to the energy efficiency of products, especially if any changes lead to increased product costs.

Conclusions

The energy consumption of game consoles is likely to rise over the next decade. The escalation in usage of media streaming could be one of the major drivers of an increase in the overall energy consumption of game consoles. A user may not need to purchase a separate device for these media playing functions, however the power consumption of the current generation HD game console when playing media is at least three times higher than a dedicated media playing device (of around 20 W or less).

There are significant opportunities for international cooperation on the various policy and technical approaches that governments can apply to improve the energy efficiency of game consoles. Although there is often different timing, policy drivers and levels of ambition in various regions, the fundamental elements of policy approach (modes of use, standby/network power levels, testing approach, APD, etc.) are similar. These policy parameters are potentially close to harmonisation internationally and will benefit from coordinated action. The major issues faced by policy officers will be the maximum power demand levels that can be established to encourage efficiency improvements. International cooperation by various regions/programs will assist in developing suitable mandatory levels which will encourage energy efficiency in game consoles without being too stringent as to remove products from the market place. It will also provide certainty for game console manufacturers who will be deploying their next generation of game console during 2013 to 2014.

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An Evaluation of the Energy Efficiency Level of Households Appliances and Lighting in Bauchi Town, Nigeria

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Abstract

Nigeria as a nation is endowed with abundance of natural resources, yet undergoing energy crisis. It is currently experiencing rampant energy poverty due to the inefficiency of the energy industry to meet the energy demands of its customers. This situation adversely affects all sectors of the economy, and particularly the housing sector with great impact on the welfare of the residents. In fact, the household energy consumption constitutes a substantial amount of societal energy demand resulting from rapid growing population, increase in living standards and the rising number of apartments in all parts of Nigeria including Bauchi. An immediate complementary measure suitable for the current Nigerian situation is to reduce energy demand which can be achieved through use of energy efficient designs, appliances and practices. On this premise, a study was undertaken on some selected households in Bauchi town to determine the energy efficiency level of appliances/lighting in use through an inventory study (case study). The result reveals a very low level of energy efficiency in appliances and lighting; therefore prompting the need to direct attention towards improving the energy efficiency level of household appliances and lighting.

Keywords: Energy resources, Energy efficiency, Appliances, Inventory study, Households, Bauchi-Nigeria.

Introduction

The issue of energy efficiency has recently become a critical one in all aspects of national development, particularly housing. This is because energy represents not only a high percentage of the running cost of a building but it also has a major effect on the thermal and optical comfort of the occupants. In Nigeria, the residential building sector is the highest energy/power consumption sector of the economy [1], and is associated with energy efficiency problems. Most household appliances and lighting are electrical and constitute a major part of the energy consumption bill [2]. To adequately address this issue, the energy performance of households needs to be improved upon, which according to Baker [3] is dependent largely on three factors of building, systems and occupants; i.e.,

i. that which is inherent in the building design,
ii. that which relates to services systems design and efficiency, and
iii. that which is due to the effect of occupant behaviour.

This shows the importance of services system /appliances design efficiency in household energy use. Unfortunately, most households' lighting installations/appliances today are inefficient due to inadequate briefing at the design stage, too much emphasis on capital cost, lack of thought during design and installation, and poor maintenance procedures. Therefore, to design or accomplish a house which has low energy running and maintenance costs, energy efficient considerations must be taken into consideration at every stage of the design process [4, 5]. The implication of this (i.e. attaining energy efficiency) is that developers can build cheaper and simpler buildings, landlords can increase rents due to added benefits of lower running and maintenance costs, tenants pay lower running and maintenance costs, and building users are more productive and healthier in the better indoor environments which can accompany energy efficiency in buildings [6].

The Need for Energy-Efficient Appliances and Lighting

A careful selection of building materials/services systems can have a dramatic effect on energy consumption and the operational costs of a building. Though, increasing number of households tends to raise energy consumption, but improving efficiencies of appliances and lighting will tend to reduce consumption. According to Zold [7], the energy consumption of household appliances is more uncertain because variations in their type and power cannot be predicted, nor can changes in the use of the building itself; and also the variation in the schedule of use of the different household appliances, and the consumption of hot water. But recent developments in energy technology has made it possible to decrease significantly the energy consumption of buildings, to create housing that is more comfortable and to implement a major decrease in emissions to the environment [2]. The housing designers can therefore do much to cut energy costs of electric lighting and other appliances by specifying and installing low energy lighting and appliances. However, the continuing shortfall between electricity demand and supply, the escalating cost of building new power plants and the competing needs for investment capital are some of the few obvious reasons why Nigeria should have improved energy-efficient households. Moreover, the prevailing rampart power shortages are attributable in part to peak demands caused majorly by lighting, air conditioning, and use of other higher energy consuming appliances (water heaters, deep freezers, washing machines, etc.) in major cities.

Continued effort by the government in establishing a lasting sustainable financial structure and incentives for energy-efficient products backed up with formidable policies and public awareness programme in this direction can help abate the efficiency problem.

In fact, appliances and lighting represent the bulk of residential energy use growth area, and has been witnessing increasing consumption levels (about 2% per year) since the 1970s [8]. In Nigeria, the residential energy is about 50% of the total electricity consumption [1]. This value compared to the global residential energy consumption as in figure 1 is due largely to the gross inadequacy of the Nigerian energy industry to provide the needed energy drive for industrial growth (leading to the almost collapsed industrial sector).

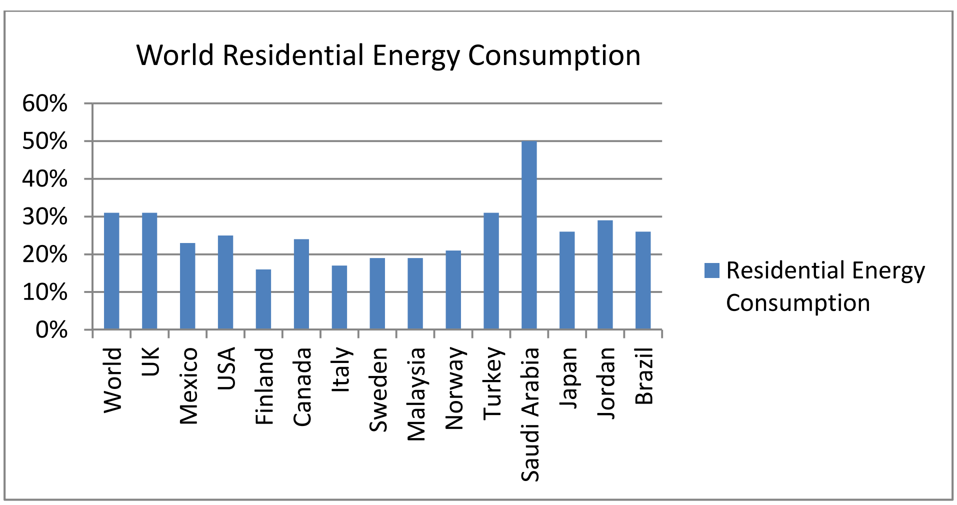

Figure 1: Worldwide residential energy consumption

Source: (Meyers et al., 2003; Nicola, 2001; Boardman, 2004; Ueno et al., 2006; Araujo et al., 2001; Kamal, 1997; Lenzena et al., 2006) in Saidur, Masjuki, Jamaluddin [9].

Household energy use occurs in the form of space conditioning, lighting, water heating, food refrigeration/freezing; and other miscellaneous energy services like clothes washing and drying, cooking and cleaning, home entertainment, etc. [10].

Space Conditioning

Space conditioning occurs in the form of heating, cooling, ventilation and humidity control. This requires more energy than any other service in both commercial and residential buildings. It accounts for more than half of total residential/commercial energy use. In residential buildings, space heating accounts for about 46% and space cooling for about 9% of energy use [10]. Because of the tropical climatic conditions of Nigeria, space heating is almost negligible except for a few mountainous regions of north central and north eastern part of the country.

There has been serious advancement in the technologies for room air conditioners in recent years. There is the new trend in household air conditioning toward central air conditioning systems in new single-family homes and multifamily buildings in developed worlds, particularly in the United States where over two-third of households are constructed with central systems. This development show a trend of increased efficiency resulting from continual free-tuning and adjustment: larger condenser and evaporator coils, better motors, improved insulation, reduced airflow-path resistance, and better fan blade design.

The energy efficiency of room air conditioners has improved due to higher efficiency compressors, improved fan designs, and larger heat exchangers. The average new unit bought today needs about 30% less electricity to deliver the same cooling as the average unit bought in early seventies [10]. Yet, many households in Bauchi, Nigeria with space conditioning facilities still maintain the old energy-inefficient types.

Lighting

In fact, a good lighting system design enhances the energy performance of buildings by offering extraordinary opportunities for energy and cost saving. Using the technologies currently available in the market, electricity use for residential lighting could be cut by about one-third [10].

The quest for increased light levels for good performance coupled with the growth in population and building construction will cause lighting demand to grow quickly, probably faster than overall electricity demand. During the last five years, the average annual increase in lamp production was about 15% compared to an 8-9% increase in electricity production [11].

However, the lighting needs of a household need to be identified, both quantitatively and qualitatively as part of the environmental programming conducted early in the project. This is because, some spaces require more of daylighting like lobbies and circulation areas with low lighting levels. But spaces used for high demanding tasks require high light levels and a glare-free environment. Such spaces may shift the designer’s attention from daylighting system to a very efficient electrical lighting system with integrated occupancy sensors and other controls [12].

In Nigeria at the moment, the illumination levels for households and other functions like classrooms, hospital examination rooms, general office, falls grossly below 100 lux as compared to other advanced nations (see table 1), except in exclusive private dwellings of the high class people with sufficient and independent power plant.

Incandescent lamps provide most lighting in the residential sector. Although, there are several improved (advanced) incandescent lamps (presently not available in Nigerian markets), they are still far less efficient than fluorescent lamps.

Fluorescent lamps are about four times more efficient than incandescent lamps, but their use in residences has been limited by their higher frost cost, unattractive light, and inability to fit in incandescent fixtures.

Table 1: Comparison of illumination standards in different countries (lux)

	U.K.	Germany	Japan	Russia	USA	China
General office	500	500	300–750	300	300	100–200
Drafting	750	750	750–1500	500	750	200–500
Classroom		300	200–750	300	300	75–150
Hospital examination room	500	500–1000	200–500		540	75–100

Source: Min, Mills and Zhang [11].

Production of CFL provides reasonably attractive light and fitting regular incandescent fixtures yet using the efficient fluorescent technology. The CFL achieves an efficiency of 61 lumens per watt, or 3.8 times the efficiency of a comparable incandescent, though they are not suitable for all residential applications. Therefore, lighting efficiency can be improved by improved lighting operation and design. That is;

i. turning off lights when not needed,
ii. using automatic (dusk-to-dawn) switches on outdoor lights, and
iii. designing fixtures that reflect rather than absorb light.

These opportunities are difficult to quantify, and their savings potential will depend on the specific situation [10]. However, the bulk of the lighting facilities in the households in Bauchi according to this study, are incandescent lamps (over 50%). This provides the opportunity to achieve great reduction in lighting energy consumption if they are replaced by CFLs.

Water Heating

Water heating accounts for about 15% of residential and 4% of commercial energy use. In residential buildings, hot water is used for personal washing (in showers and baths), clothes washing, dishing washing and other miscellaneous uses.

The efficiency of residential-size water heaters has improved in recent years due largely to increased tank insulation, smaller pilot lights, and improved heat transfer from combustion gases to the water in the tank. Other methods of improving water heating efficiency include demand reduction, retrofits to existing units, and technical improvement in new units [10]. But, due to the hot climatic region of N. E. Nigeria where Bauchi is located (except a few mountainous regions), the water heating energy demand is not much emphasized.

Food Refrigeration/Freezing

About 10% of residential energy use goes into keeping food cold. The energy efficiency of food refrigeration equipment has improved greatly in the last 10-20 years. Among these improvements are the use of polyurethane foam rather than fiberglass insulation, more efficient motors and compressors, improved door seals, and improved air flow between cold coils and food compartments.

Many other technologies such as improving compressor design, installing separate compressors for the freezer and the refrigerator (dual compressors), and moving the compressor from the bottom to the top of the refrigerator to reduce heat flow from the compressor into the refrigerator could be considered to improve energy efficiency [10]. In fact, there is a gradual ‘phase-out’ of inefficient refrigeration appliances in the Nigerian households as the old ones (no longer in the market) are being replaced by the new energy-efficient types.

Other Energy Services

There is a wide range of energy services provided in residential buildings other than space conditioning, lighting, water heating, food refrigeration and freezing. These include clothes washing and drying, cooking and cleaning, home entertainment, etc. These miscellaneous energy services account for about 13% of residential energy use [10]. Except for cooking, majority of these 'other energy services' in Bauchi town are energy-efficient types as available in the market.

Approaches and Methods

The objective of this study is to evaluate the energy efficiency level of households' appliances and lighting in Bauchi town, Nigeria as a prelude to proffering ways to improving household energy efficiency. To accomplish this effort, an inventory (case study) of households' appliances and lighting was undertaken in twelve (12) selected houses from the three (3) geographical districts of Bauchi town between October and December, 2010. That is, two (2) housing units from each housing estate; and two (2) housing estates from each of the three (3) geographical districts (Bauchi, Galanbi & Zungur) of Bauchi (metropolis) LGA.

In the process, the items were categorized as lighting, cooling, heating, refrigeration, cooking, computers, electronics; and 'others' which comprise of pressing iron, blender, toaster, deep fryer and washing machine as identified in all houses understudied.

These items were further classified as 'ordinary' (i.e. not efficient), 'efficient-type,' and 'undetermined' for ease of analysis (see table 2).

The result obtained was further subjected to appliances description categorization *scale of 1-5* (% range) to measure energy efficiency from 'Very unsatisfactory' to 'Very satisfactory' for the subsequent inventory analysis:

Table 2: Classification of Appliances/Lighting

Appliances Classification	Definition
1. Ordinary	Appliances with higher energy consumption ratings. Usually of old technology, either labeled or determined by deduction based on none performance at low voltage levels.
2. Efficient	Appliances with lower energy consumption ratings compared with existing types with higher ratings. Usually of modern technology, either labeled or determined by deduction based on very low voltage performance.
3. Undetermined	Appliances that the energy consumption rating is not labeled and could not be determined by deduction.

Categorization scale: 1- 5 (% range)

	Unsatisfactory		**Satisfactory**	
(0-20%)	(21-40%)	(41-60%)	(61-80%)	(81-100%)
Very unsatisfactory		**Neutral**		**Very satisfactory**

Source: Hussaini [13]

Result and Discussions

The lighting appliances were categorized into incandescent and fluorescent lightings respectively as recorded in table 3. Meanwhile, the incandescent lamps are generally described as 'ordinary' (i.e. not efficient) since there are no efficient incandescent bulbs in Bauchi market for now. On the other hand, the fluorescent lighting can either be 'ordinary' or 'efficient-type'. The 'efficient-type' refers to the compact fluorescent lights (CFL).

From table 3, it is observed that there were one-hundred (100) incandescent lamps and ninety-nine (99) fluorescent lamps in the twelve (12) households. Out of the ninety-nine (99) fluorescent lights, twenty-six (26) (i.e. 26.3%) were the ordinary type while seventy-three (73) (i.e. 73.7%) were the CFLs. That is, in a total of one hundred and ninety-nine (199) lighting points, only seventy-three (73) points are fixed with energy saving bulbs. This accounts for only 36.7% lighting efficiency. This level of energy efficiency in lighting which is a fundamental aspect of energy consumption in Nigeria and based on the above scale is *unsatisfactory.*

The cooling appliances are categorized as fans and air-conditioners respectively. From table 3, it is clear that there were sixty-eight (68) fans and five (5) air-conditioners (ACs) in the twelve (12) households surveyed. Fifty-nine (59) (i.e.86.8%) of the fans are 'ordinary' while only nine (9) (i.e. 13.2%) are the 'efficient-type.' Meanwhile, all the five (5) ACs (i.e. 100%) were observed to be energy efficient-type. That is, in a total of seventy-three (73) cooling appliances, only fourteen (14) (i.e. 19.2%) are energy efficient. This level of energy efficiency is *very unsatisfactory* considering the importance of cooling appliances which is next to lighting in terms of consumption level in Nigeria.

Table 3 indicates that there are seven (7) room heaters and all are 'ordinary' type; ten (10) water heaters and all are 'ordinary' type; and fifteen (15) water boiler/kettles, out of which two (2) are efficient-type (13.3%) and thirteen (13) are 'ordinary' type (86.7%). This implies that only two (2) (i.e. 6.3%) of the thirty-two (32) heating appliances are energy efficient. This is a *very unsatisfactory* level of energy efficiency.

The refrigeration group of appliances includes the fridge and the deep freezer. There were fourteen (14) fridges in all; out of which nine (9) are 'ordinary' type and five (5) are efficient-type. The deep freezers are thirteen (13) in all, and only four (4) are 'ordinary' type while nine (9) are 'efficient-type'. That is, in a total of twenty-seven (27) refrigeration appliances, only fourteen (14) (i.e. 51.9%) are energy efficient. The energy efficiency in this scenario is on the *neutral* level (i.e. neither satisfactory nor unsatisfactory).

As indicated in table 4, four (4) different modes of cooking were identified in the households surveyed. Among them are three (3) electricity-type cooking appliances, one (1) gas-type cooking appliance, one (1) kerosene-type cooking appliance and wood fuel (one-type) for cooking. Except for the electrical appliances, all others were classified as undetermined.

The three (3) electricity-type appliances are; electric cooker, electric stove and micro-wave oven. There were three (3) electric cookers and all classified as 'ordinary'; six (6) electric stoves, all classified as 'ordinary'; and one (1) micro-wave oven which is classified as 'efficient-type'. That is, among all the ten (10) electricity-type cooking appliances, only one (1) (i.e. 10%) is energy efficient. This is a *very unsatisfactory* level of energy efficiency.

Table 3: Inventory of Appliances in Use in 12 Selected Housing Units

Factors	Parameters	Description	Frequency	Percentage (%)
1. Lighting	Incandescent	Ordinary	100	100
		Efficient type	-	-
		Undetermined	-	-
	Fluorescent	Ordinary	26	26.3
		Efficient type	73	73.7
		Undetermined	-	-
2. Cooling	Fans	Ordinary	59	86.8
		Efficient type	09	13.2
		Undetermined	-	-
	Air Conditioners	Ordinary	-	-
		Efficient type	05	100
		Undetermined	-	-
3. Heating	Room Heater	Ordinary	07	100
		Efficient type	-	-
		Undetermined	-	-
	Water Heater	Ordinary	10	100
		Efficient type	-	-
		Undetermined	-	-
	Water Boiler/Kettle	Ordinary	13	86.7
		Efficient type	02	13.3
		Undetermined	-	-
4. Refrigeration	Fridge	Ordinary	09	64.3
		Efficient type	05	35.7
		Undetermined	-	-
	Deep Freezer	Ordinary	04	30.8
		Efficient type	09	69.2
		Undetermined	-	-

There were sixteen (16) computer appliances identified in the twelve (12) households under study classified as PC/accessories and Laptops (see table 4). There were eight (8) PCs out of which three (3) are 'ordinary', three (3) 'efficient-type', and two (2) 'undetermined'. All the identified eight (8) laptops are classified as 'efficient-type'. That is, eleven (11) (i.e. 68.8%) of the sixteen (16) computer appliances are energy efficient. This score is a *satisfactory* level of energy efficiency according to the scale of measurement.

There were fifty-two (52) electronic appliances as shown in table 4, classified as television sets, satellite decoders, and DVDs/Video/Radio players. There were twenty-seven (27) television sets, out of which twenty-three (23) are 'ordinary' and four (4) 'efficient-type'. The satellite decoders are ten (10), out of which are two (2) 'ordinary', seven (7) 'efficient-type', and one (1) 'undetermined'. The DVD/video/radio players are fifteen (15), out which six (6) are 'ordinary' and nine (9) 'efficient-type'. That is, in a total of fifty-two (52) electronic appliances, only twenty (20) (i.e. 38.5%) are energy efficient. This level of energy efficiency score is *unsatisfactory*.

Table 4: Inventory of Other Miscellaneous Energy Services

Factors	Parameters	Description	Frequency	Percentage (%)
5. Cooking	Electric Cooker	Ordinary	03	100
		Efficient type	-	-
		Undetermined	-	-
	Electric Stove	Ordinary	06	100
		Efficient type	-	-
		Undetermined	-	-
	Gas Cooker	Ordinary	05	100
		Efficient type	-	-
		Undetermined	-	-
	Micro-wave Oven	Ordinary	-	-
		Efficient type	01	100
		Undetermined	-	-
	Kerosene Stove	Ordinary	-	-
		Efficient type	-	-
		Undetermined	17	100
	Wood Fuel	Ordinary	-	-
		Efficient type	-	-
		Undetermined	11	100
6. Computers	PC and Accessories	Ordinary	03	37.5
		Efficient type	03	37.5
		Undetermined	02	25
	Laptops	Ordinary	-	-
		Efficient type	08	100
		Undetermined	-	-
7. Electronics	Television Sets	Ordinary	23	85.2
		Efficient type	04	14.8
		Undetermined	-	-
	Satellite Decoders	Ordinary	02	20
		Efficient type	07	70
		Undetermined	01	10
	DVDs/Video/Radio Players	Ordinary	06	40
		Efficient type	09	60
		Undetermined	-	-
8. Others	Pressing iron, Blender. Toaster, Deep fryer.	Ordinary	04	18.2
		Efficient type	18	81.8
		Undetermined	-	-

In the category of 'other' appliances as in table 4, we have the pressing iron, blender, toaster, deep fryer and washing machine; all together twenty-two (22) in number. Among these, four (4) are 'ordinary' while the remaining eighteen (18) are 'efficient-type'. That is 81.8% energy efficiency score which is *very satisfactory*. The effect of this result is negligible as most of the houses do not possess these appliances.

The cumulative result reveals a very low level of energy efficiency in household appliances in Bauchi. Invariably, lighting and all appliances of cooling, heating, cooking, refrigeration and electronics are in the category scores of very unsatisfactory, unsatisfactory or neutral. These scores fall below the desirable satisfactory level necessary for the accomplishment of good energy efficiency practice in the households.

The finding has also indicated that cooking in Bauchi, typical of Nigeria and other underdeveloped countries (Africa) has both the modern and traditional methods incorporated in a majority of the households. The modern ways include the use of electric cooker, electric stove, gas cooker, micro-wave oven etc., while the traditional method includes the use of kerosene stove and wood as fuel. The latter is a substitute and an alternative to the former in most cases because of the scarcity and high price of the electric energy and cooking gas required to utilize these appliances. Meanwhile, kerosene and wood are relatively cheap and readily available. As a result, almost all households subscribe to this substitute. However, it is discovered that among the electricity-type appliances only ten percent (10%) are energy efficient. Improving the reliability of power supply along with the use of energy efficient appliances would assist to remedy this situation.

Conclusion

Concisely, it is apparent that the lighting appliance is the dominating appliance in use in all the households; an indication that lighting is a very important part of our energy need. Therefore, promoting efficiency in lighting alone can lead to immediate enormous gains. In general, the government must ensure the promulgation of policies/measures that would lead to the replacement of the existing inefficient appliances either by retrofitting, halting the production/importation of inefficient appliances, and/or adopting the following improvement strategies (according to literatures) to remedy the appalling situation of households appliances and lighting energy efficiency;

- Reduce energy consumption by substitution of electric heating by other energy sources.
- Reduction of energy consumption of air conditioning systems and lighting.
- Reduction of energy consumption of electronic equipment in stand-by mode.
- Development of windows with heat transfer coefficient less than $2W/m^2k$ and the development of special glass with increased reflection and selective absorption and emission abilities.
- Consideration of the passive energy design strategies for natural lighting (daylight) and natural ventilation; and the development of measurement techniques for evaluating the energy efficiency of buildings.
- Setting energy efficiency standards by the controlling authority by imposing minimum level of efficiency though manufacturers are not usually disposed to it because of administrative and adaptation costs.
- Stimulating the supply of efficient products by technology procurement, i.e. offering incentives to manufacturers to take part in development and diffusion of highly energy efficient products.

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PROMOTING ENERGY EFFICIENCY REFRIGERATORS IN GHANA

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ABSTRACT

Ghana launched a Refrigerator Rebate and Exchange Scheme in September 2012 as a tool to reduce energy consumption and address the environmental impacts of old refrigerators. The West African nation has taken significant strides in promoting energy efficiency in recent times by instituting regulations and other innovative market tools to curb the rising demand for energy.

This paper discusses the implementation of a refrigerating appliance transformation project, which intends to promote more energy efficient appliances on the Ghanaian Market. This project, which is at its mid-term, is already making significant impact and proves that market transformation schemes in developed countries could equally work in a developing country such as Ghana when modified to suit local conditions.

Introduction

In most developing countries, the demand for electrical energy is fast on the heels of installed generation capacity. Ghana is experiencing a similar situation in view of its growing population and attendant economic growth. As the standard of living in any country improves, residential electricity demand is expected to grow rapidly as more people purchase TVs, refrigerator, air conditioners and other appliances. This is the case of Ghana, which achieved a growth rate of 7.1% in 2012 against a global growth of 3.2% and Sub-Saharan Africa growth of 4.8% [1]

As expected, electricity demand in Ghana is also growing at an average rate of 11% annually. However, wastage in the end-use of electricity is estimated at about 30% [2]. The main electricity consuming sectors in the country are the industrial, commercial and the residential sectors. As shown in figure 1, the industrial sector continues to be the highest consumer of electricity followed by residential and the commercial sectors respectively.

The Government has therefore committed to increase the total electricity output to 5,000 MW by 2015 to meet the growing demand for electrical energy[3].

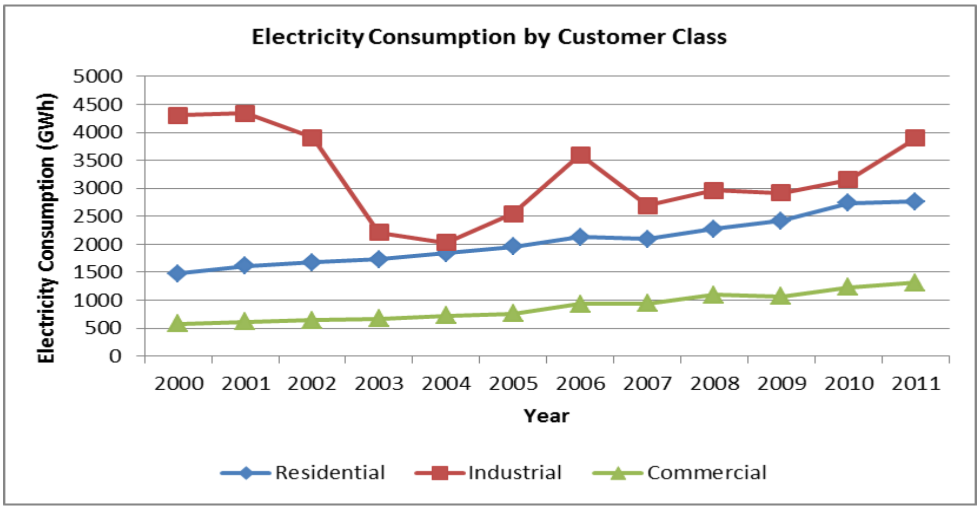

Figure 1: Electricity consumption from 2000 – 2011 Source: Energy Commission, 2013

There is however great potential to also reduce national demand through energy efficiency programmes. In 2007 when the country experienced a power crisis, there was a justification for the Government of Ghana to improve energy efficiency by distributing six million pieces of compact fluorescent lamps (CFLs) free of charge to replace an equivalent number of incandescent bulbs throughout the country. This intervention saved approximately 124.2MW in peak demand and about 112,320 tCO_2 per annum [4]

Another achievement of the exercise was the significant increase in the penetration of CFLs in the country. As at 2009, the penetration of CFLs had increased from 20% in 2007 to 79%, with a corresponding decrease in the penetration of incandescent lamps from 58% in 2007 to just 3% in 2009 [4].

Energy efficiency standards and labelling regulations have been introduced for lighting, domestic refrigeration and air conditioning Ghana is now operating a mandatory appliance standards and labelling regime under which importers and retailers of air conditioners, compact fluorescent lamps (CFLs) and domestic refrigerators are required to import and sell only products that meet minimum energy efficiency and performance standards. Legislative instruments (LI's) prohibiting the importation and sale of inefficient incandescent bulbs, used refrigerators and air conditioners has also been introduced to ensure that only domestic appliances that meet the minimum energy efficiency standards enter the Ghanaian market. The energy efficiency LIs that have come into effect in Ghana are:

- Energy efficiency Standards and Labelling (Non-ducted Air Conditioners and Self ballasted fluorescent Lamps) Regulations, 2005 (LI 1815)
- Energy Efficiency Standards and Labelling (Household Refrigerating Appliances) Regulations, 2009 (LI 1958)
- Energy Efficiency (Prohibition of Manufacture, sale or Importation of Incandescent Filament Lamps, Used Refrigerator, Used Refrigerator-Freezer, Used Freezer and Used Air Conditioner) Regulations, 2008 (LI 1932).

These first sets of LI's focused on Light bulbs, refrigerators and air conditioners because of the fact that they are the major sources of electricity consumption in the domestic sector of the economy.

The first two legislative instruments 1815 and 1958 prohibit the importation into the country of air conditioners, refrigerators and CFLs that are not properly labelled and do not meet specified minimum energy efficiency and performance standards. The purpose of the labels is to help the public make informed decisions about the appliances they intend to purchase.

The third legislative instrument (LI 1932) prohibits the importation and sale of incandescent lamps, used air conditioners and used refrigerators in the country. This legislative instrument has succeeded in eliminating the energy inefficient incandescent lamps from the Ghanaian market and will eventually do the same to used air conditioners and refrigerators. In addition to these actions, programmes have been implemented to improve the power factors of commercial buildings and industrial facilities to at least 0.9.

A study conducted by the Centre for Scientific and Industrial Research (CSIR) on consumption of Refrigerating appliances established that refrigerators consume an average of 1,140 kWh/year in Ghana, or approximately three times more energy than the maximum allowed in countries with robust standards and labeling programs.[5] Such inefficient appliances result in US$50 to US$100 per year of potentially unnecessary electricity expenses for a typical owner, which he/she can ill-afford. The wasteful consumption of electricity results in more than 0.7 tons per year of CO_2 emissions per appliance, and uncontrolled release of ozone depletion substances (ODS) from used appliances can result in the equivalent of another 2 tons of CO_2 every time an inefficient, used appliance is improperly disposed or replaced.

Refrigerators and Freezers account for as much as 25% to 30% of household electricity bill as such there is room to substantially reduce household electricity consumption in the Country[5].

It is for these reasons that the UNDP and the Global Environmental Facility is supporting Ghana through a project titled ***"Promoting Appliance Energy Efficiency and Transformation of the Refrigerating Appliances Market in Ghana"***. The project involves among others the introduction of energy efficiency standards and labels for refrigerating appliances, establishment of test facilities and market tools such as rebate schemes. The implementation of the project indicates that the potential exist in developing countries to adapt measures that have been successful in some developed countries for the local environment.

Implementation of the Refrigerator Project in Ghana

Based on the significant strides made in the area of energy efficiency, UNDP-GEF is supporting a project titled: ***"Promoting Appliance Energy Efficiency and Transformation of the Refrigerating Appliances Market in Ghana".*** The global objective of the project is to reduce Ghana's energy-related CO_2 and ozone depleting substance (ODS) emissions by mitigating the demand for energy in household refrigeration and by encouraging recovery, recycling and/or destruction of environmentally damaging refrigerants.

The project has eight components namely:

- Component 1 - Strengthening of regulatory and institutional framework
- Component 2 - Design of certification, labelling and enforcement systems
- Component 3 - Training and public outreach
- Component 4 - Establishment of refrigerating appliance test facility
- Component 5 - Used appliance collection and disposal facilities
- Component 6 - Efficiency program evaluation and monitoring capacity development
- Component 7: - Conduct of refrigeration appliance rebate and exchange program
- Component 8: Financial design of follow-up national market transformation programs

The project commenced in July, 2011 and has a life-span of three years. The significant progress made under each of the eight components named above at the half life point of the project is discussed in the following sectionsof this report .

Component 1 Strengthening of regulatory and institutional framework

The project has fostered strong collaboration between Ministries, Departments and Agencies required to develop and implement regulations that will provide a good foundation to transform the refrigerator market. The Ministries of Energy, Environment and Trade are providing policy direction whilst the Energy Commission, Environmental Prevention Authority and the Ghana Standards Authority is involved in planning, implementation and enforcement. All such institutions have been involved on the Steering Committee of the project to promote institutional buy-in, provide general direction and enhance quick feedback on deliverables.

The Energy Commission and the Ghana Standards Authority in particular have also built their capacity in developing regulations and policy options to address the issues involved. This has been done through seminars, workshops and practical engagement in the development of the regulations.

Component 2 - Design of certification, labelling and enforcement systems

The Ghana Standards Authority has adopted GS IEC 62552 which outlines the test methods for checking the performance characteristics of household refrigerators. The Country has also developed labels to reflect the particular circumstance of Ghana where black stars have been used to indicate the efficiency rating. In Ghana, the black star, which is a prominent feature in the national flag, is recognised for its relevance in building confidence. As such the more stars on the label the more efficient the refrigerator. Fig 2 shows a sample of the label for refrigerating appliances.

In 2011, the labelling of new refrigerators and freezers for sale was commenced. The take-off of the mandatory labelling requirement commenced with a few market leaders who were already importing refrigerating appliances that met the minimum energy performance standards. In the few months after enforcement of the regulations, the Commission continued to educate importers and retailers on the requirements. As part of activities to enforce the regulations, the Energy Commission has also trained custom officials at all the major entry points to stop at the point of entry all refrigerators without labels from entering the market. Custom officials have also been educated on the labelling requirements.

The Inspectorate Unit at the Energy Commission has also received a boost in their personnel and capacity to conduct compliance monitoring. There is however the need to recruit more staff to this department.

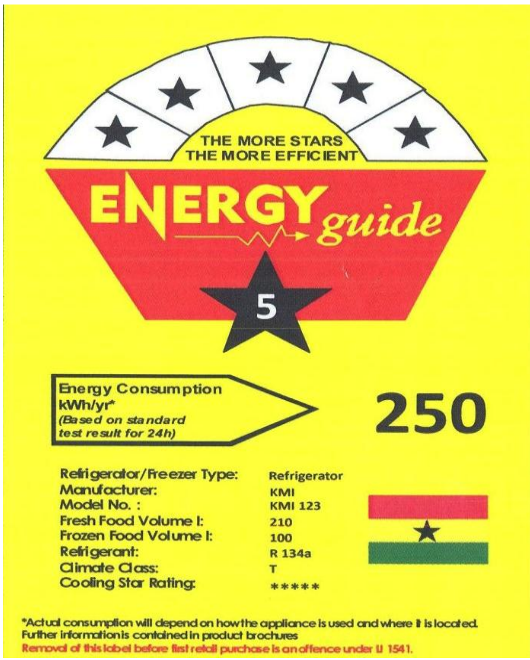

Fig 2: Energy Efficiency Standards and Label Source: Energy Commission

Component 3 - Training and public outreach

Even though most Ghanaians are familiar with appliance labels due to previous labelling requirements on CFLs and air conditioners, most customers could not realise the huge potential for energy savings with the high efficient refrigerating appliances. The project had employed a mix of strategies to publicize the refrigerator labels and its benefits to a greater section of the public. Publicity was therefore focused on Radio, TV, Newspapers and Billboards. For radio, a 60-second jingle was produced to broadcast the newly introduced labels for refrigerators/freezers and their benefits. Several radio interviews were granted on morning shows at major radio stations with wide listenership.

On television, a documentary was produced to underscore the impacts of old refrigerators on energy use and environment. It also addressed the newly introduced energy efficiency labels with explanations on the useful information that could be gleaned from it to enable customers make informed purchasing decision. In addition, a captivating animation on the labels was commissioned and shown on TV for over two months to simplify the message and create an appeal to the whole family. The project also employed the large captive power of local sitcoms and incorporated aspects of energy efficiency and the newly introduced labels in the story line. This was merged in the running story of the sitcom which was aired in five weekly episodes. All the videos acquired have become very useful tools during training seminars.

To compliment radio and television, newspaper articles and adverts were also employed to target the mid to upper segments of the public. In addition to all the above, retailers and refrigerator technicians are continuously trained by the Energy Commission to enhance their knowledge and selling skills of refrigerators.

Component 4 - Establishment of refrigerating appliance test facility

The project is in the process of establishing a refrigerator test facility that will enhance enforcement of the refrigerator standards and labelling. With the establishment of the refrigerator test facility, any suspicious item on the shop floor can be picked up and tested for compliance. Samples can also be collected from imported units to confirm their energy performance levels. It is expected that the facility will be operational by the end of 2013.

Component 5 - Used appliance collection and disposal facilities

A company has been selected to provide support in collecting turned-in refrigerators, recovering refrigerants and properly dismantling the refrigerators for recycling. The company has invested in a stage-1 refrigerator recovery facility specifically for the project. This facility has the capacity to recover refrigerants from 200 refrigerators per day. The refrigerator dismantling company is responsible for transporting all refrigerators that are turned-in as part of the refrigerator rebate and exchange scheme.

Component 6 - Efficiency program evaluation and monitoring capacity development

Monitoring and evaluation plays a critical role in the implementation of the Refrigerator Energy Efficiency Project. In order to realize the indicators ascribed to the various outcomes, project monitoring has been tailored to derive specific results that would feed into the evaluation process as well. The project has developed a monitoring and evaluation matrix to collect data that will assist in evaluating the scheme to gauge the impacts.

Component 7 - Refrigeration appliance rebate and exchange program

A refrigerator rebate and exchange scheme was launched in the Country on 19th September 2012 on a pilot basis in the regional capital of Accra. The rebate programme is geared to provide an incentive for buyers to purchase new energy star refrigerators to replace old high consuming refrigerators. In designing the refrigerator rebate scheme, a review of similar programmes in the U.S.A, Malaysia and Brazil were studied and some adjustments were made to accommodate the local conditions in Ghana.

Under the scheme, customers send their old but functional refrigerators to the participating shops where tests are carried out to confirm functionality. Customers who pass the test are awarded an instant discount of US$75 towards the purchase of a 2-star rated refrigerator or US$100 for the purchase of 3-5 star rated refrigerators. Customers then pay the difference after the face-value on the refrigerator/freezer has been discounted. The project has made an arrangement with a Bank to provide consumer loans for customers who still require financial support to complete the purchase.

All returned refrigerators are collected by the dismantling company at scheduled times. The retailer will then send their sales reports to the Energy Commission to claim the total amount of discounts offered for the period. Verification is done at the Energy Commission to confirm that the dismantling company has received all the turned-in refrigerators covering each claim before payment is made.

To promote the scheme, the project invested in a number of advertisements on the rebate scheme on TV, radio and newspapers, and participating retail outlet. Various marketing channels of the retail outlets were also used to publicize the scheme. After three months of implementing the scheme, a little over 1000 refrigerators were turned-in for purchase of energy efficient refrigerators at the two participating retail outlets, which operated a total of 17 outlets in the city.

Based on the success of the pilot phase which was restricted to the national capital and only two retail shops was scaled-up nationwide in May, 2013. The number of retailers was increased from 2 to 4 and all regional capitals were included.

Component 8: Financial design of follow-up national market transformation programs

The refrigerator project is a work in progress and so far the results show that certain portions of the project could be replicated to fit not only national conditions but also the African sub-region.

Initial Results

The following are some of the major results from the project:

- A dipstick survey conducted by the Energy Commission indicated that out of 1,000 people who were interviewed, over 90% were aware of the energy efficiency labels.
- The major household appliance dealers in the country have also been trained on the energy efficiency labels and the potential to use the label to market their products.

- Also, over 600 refrigerator technicians have been trained in proper maintenance of refrigerators to prevent emission of refrigerants during repairs. The technicians were also taken through the details on the labels and the potential benefits to clients.
- The project had recovered over 2,200 old high energy consuming refrigerators and replaced it with energy efficient appliances after six months of implementing the pilot phase.

Challenges

- Enforcement on the ban on the importation of used refrigerating appliances had to be postponed for four years after the law was established due to petition by importers to Government to scrap the law. The importers of used Government were initially strongly opposed to the law and it required numerous rounds of meetings with Government officials to address their issues. The Energy Commission has been instrumental in providing training to members on the need for energy efficient appliances and providing some channels to enable them to market new appliances. The target is to ultimately promote the establishment of a local manufacturing facility in Ghana that will reduce prices of new refrigerators and tap into the wide distribution network of the importers.
- Due to the high influx of substandard appliances prior to establishment of regulations, there is a general perception from customers that used appliances are more durable. A lot of work therefore remain to sieve out all the low-quality appliances marketed as new and promote quality brands to enable customers to make the right switch.

Conclusion

The project will continue to use the lessons learnt from the initial phase of implementation to continually enhance the impacts expected from the intervention. The initial feedback promises positive results for the remaining project period. There exist a potential electricity savings of 216MWh and CO_2 reduction of 251.6 kilotonness over the project period if a substantial amount of over 50,000 units of refrigerators could be replaced[6]. This is certainly an interesting prospect for making energy efficiency the new power generation plants to support the slow pace of investment in power generation capacity.

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The West African Energy Efficiency Policy: Using Efficiency To Achieve Universal Energy Access

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Abstract

The West African energy system is facing serious interrelated challenges of energy access, energy security and climate change adaptation and mitigation. To address these multiple challenges, ECOWAS has taken action to adopt and implement a Regional Energy Efficiency Policy. The ECOWAS energy efficiency action plan is based on five flagship energy initiatives, each including policy, capacity building, awareness raising and financing elements.

Introduction

The ECOWAS region, comprising 15 countries[1] in West Africa, is faced with a multifaceted energy crisis. About 60% of the population does not have access to electricity, and over 80% cooks with traditional biomass causing serious health and environmental problems.

The ECOWAS region governments have initiated an ambitious programme to achieve “Sustainable Energy for All”, within the framework of the UN Secretary General’s initiative. The ECOWAS approach is built on three regional policies: access to energy, renewable energy and energy efficiency.

The regional energy efficiency policy (EEP developed by the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), was approved by the Ministers of Energy in October 2012. The EEP strategy focuses on policy, capacity building, awareness raising and finance. The EEP is targeting areas where short and medium term action can bring substantive impact on economic development and well being of the region’s people. For each target, the EEP action plan includes an initiative.

The five targets and initiatives of EEP are:

- Phase out inefficient incandescent lighting;
- Reduce electricity distribution losses to under 10%;
- Achieve universal access to safe, clean, affordable, efficient and sustainable cooking;
- Adopt initial region-wide standards and labels for major energy equipment;
- Create instruments for financing sustainable energy.

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[1] ECOWAS is a Regional Economic Community, the West African institution equivalent of the European Union. The ECOWAS member states are Benin, Burkina Faso, Cape Verde, the Gambia, Ghana, Guinea, Guinea Bissau, Ivory Coast, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo ECOWAS has built partnerships with major public and private organizations to implement the EEP action plan, including: European Commission, ADEME, AEA, UNDP, ENERGIA, Copper Alliance, UNEP en.lighten, and CLASP.

The Energy and Development Challenge in West Africa

ECOWAS countries are faced with an immense development challenge. They must meet development needs - job creation, education, health, drinking water – for a rapidly growing population of more than 300 millions, despite the numerous institutional weaknesses of the region.

Supplying access to clean energy involves the following. To:

- Allow everyone access to vital services
- Guarantee the reliability of energy supply and distribution systems
- Maximize the contribution of energy to economic development, to gender equality and to social equity
- Protect the local and global environment from the negative aspects of energy value chains.

Indeed, it will not be possible for the region's countries to progress without electricity in schools, adequate mechanical power for industry and water pumping, or without sustainable supply of clean fuels for cooking. Nonetheless, today, 2/3 of the population of the region does not have access to electricity [1], nor to mechanical power other than from human and animal muscular force.

Furthermore, over ¾ of families cook using wood or charcoal, with rudimentary stoves that emit highly harmful smoke [2], affecting both the women who cook and the young children that accompany them (See Fig 1). Two energy related tasks – carrying water and collecting cooking fuel – require substantial amounts of time from women and girls, limiting their opportunities for educational and economic activities, and often exposing them to life threatening dangers.

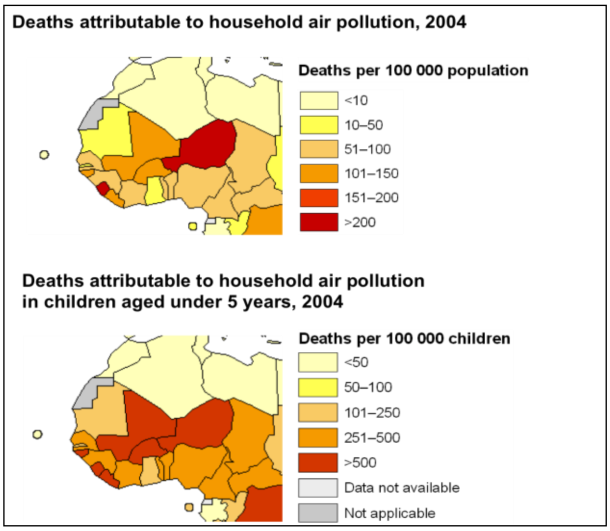

Figure 1: Deaths attributable to household air pollution, Source: World Health Organization

The region's governments, acting within the framework of ECOWAS have clearly understood this challenge. Thus, in January 2006, ECOWAS adopted the ECOWAS-UEMOA "White Paper for a Regional Policy for Increasing Access to Energy Services for Populations in Rural and Peri-Urban Areas in Order to Achieve the Millennium Development Goals" [3], that included ambitious objectives for access to energy by 2015, for electricity, cooking, and power for productive activities and social services. Because of weak institutions and lack of means and political commitment, the region has not progressed as rapidly as planned to achieve these goals. Consequently, ECOWAS acted to create the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) in 2007. ECREEE is responsible for leading regional action in favour of renewable energy and energy efficiency. ECREEE - with the support of the European Commission, ADEME, the UNDP, Austria and Spain – has acted to harness the enormous potential of energy efficiency, through a five-step approach:

- stock taking missions in the fifteen countries of the region. These missions reached the following main conclusions:
    - Most of the region's countries, to different degrees, suffer from a crisis situation in the energy sector. Power cuts affect users for an average of 56 days per year. The World Bank estimates that the resulting loss in production amounts to a reduction of growth

by 2% annually[2]. Supply of cooking fuels is in danger in the long term: indeed, many city dwellers already spend as much for fuel as for food.

  - The energy efficiency potential in the region is quite substantial. With just two measures – phasing out incandescent lamps and reducing electricity distribution losses to under 10%[3] - savings of as much as 20% overall could be achieved.

  - The majority of countries have not acted effectively to capture the potential of energy savings, with less than half disposing of institutions responsible for implementation of concrete programs, and only Ghana having achieved substantial results.

- drafting of a political strategic document on energy efficiency on the basis of data collected;

- validation of the draft energy efficiency strategy by the competent national political authorities;

- submission for consideration and adoption by the region's Energy Ministers;

- implementation of the policy.

ECOWAS and ECREEE have now engaged the last step of this process, with implementation of the Energy Efficiency Policy's (EEP) recommendations.

A policy and an action plan for energy efficiency

On the basis of the stock taking conclusions, ECREEE developed a draft policy document on energy efficiency. This included the current situation, analysis of energy efficiency at the level of major economic sectors (transport and city planning, industry and services, households) and the public action necessary to capture the potential savings. The document concludes with a regional strategy composed of: political and policy actions; awareness raising for energy efficiency; human and institutional capacity building; financial measures; an action plan.

The EEP includes five concrete initiatives, each with partners, an action plan, and a financing framework in order to maximise the probability of success of the policy, given that Ministerial approval of a policy document does not guaranty implementation. These initiatives focus on lighting, electricity distribution, cooking, standards and labels, and finally environmental finance for sustainable energy.

1. The initiative on lighting focuses on the one electrical appliance that represents the single biggest component of power consumption in West Africa: indeed, for the region's electrified households, lighting is the first, and sometimes the only, use of electricity [4]. The initiative aims at replacing incandescent bulbs with high efficiency bulbs: CFLs in the short term. Ghana has already carried out a successful programme on lighting, substantially achieving market transformation, with a 70% penetration in the market of standard neon and CFL bulbs. The Ghana programme consisted of a massive initial distribution of 5 million CFLs, coordinated with an awareness raising campaign. Teams spread out across the country to remove and replace the incandescent bulbs, and destroy them with steam rollers in city and village public places. The programme achieved a 10% reduction in peak power demand, with corresponding savings for the government in avoided investment in power plants and lines more than paying for the programme. It is expected that the key elements of the Ghanaian programme can be replicated throughout the region.

2. The initiative on electricity distribution is of a different nature. Whereas lightbulbs concern tens of millions of households, distribution losses directly concern only a few dozen enterprises. The nature of the challenge is also different. While lighting is a low cost consumer good, distribution systems are highly capitalistic and complex. The distribution infrastructure of the region suffers from chronic underinvestment, as well as insufficient maintenance. The initiative aims at supporting utilities in implementing global programmes in two areas. Investment in infrastructure – power lines,

[2] Fact Sheet -The World Bank and Energy in Africa: http://go.worldbank.org/8VI6E7MRU0

[3] Current distribution losses in the region vary from 15% to 40%, as compared to losses in developed countries of around 7%.

transformers, sub-stations – and institutional capacity for preventive maintenance, effective billing and collection of payment. Guaranteeing payment for services is a major challenge, since non-payment and theft of electricity are so widespread. In some cases, technical solutions can play a role in improving commercial performance. Prepayment meters have proved to be effective in aiding households in controlling budgets for electricity. High voltage distribution systems, that replace 220 V lines with higher voltage lines, both reduce line losses and make theft more difficult. The potential gains are large. Whereas well run systems have distribution losses of approximately 7 to 8%, distribution losses in West Africa range from 15% to 40%[4].

3. Another initiative addresses the complex challenge of cooking, an absolutely vital issue. Despite its importance, long term supply of cooking fuel is in danger in West Africa. The forest resources that supply wood and charcoal are declining, due to the conjunction of a variety of factors: conversion of forests to agricultural land; desertification due to the advance of the Sahara; climate change; overcutting near cities that prevent regrowth. Liquid petroleum gas, the major alternative to wood and charcoal fuel, is too expensive for the majority of the population[5]. The cooking initiative aims to address sustainability of cooking at each link of the cooking value chain as shown in Figure 2

Sustainable forest management → controlled wood cutting → (improved charcoal transformation) →

Optimised transport and distribution → clean and efficient cook stoves

Fig 2: Title

4. The region also intends to create a coherent regional system of standards for energy using equipment. Such a system is an essential basis for consumer labels for energy efficiency, for testing and certification of products, and for Minimum Energy Performance Standards (MEPS). In the short term, the newly established regional Technical Committee on Standards and Labels plans to concentrate on MEPS to support the lighting initiative.

5. Finally, the initiative on environmental finance aims to mobilise the various existing financial instruments that could provide support for energy efficiency efforts. The most important is climate finance, since energy efficiency translates directly into reduction of emissions of the Green House Gases carbon dioxide and methane in most cases. In West Africa, reduction of methane is particularly pertinent, since methane emissions from uncontrolled waste dumping could be converted into useful fuel, notably for cooking, as well as for power generation. Furthermore, proper recycling of refrigerant gases (CFLs) could benefit from the financial instruments of the Montreal Protocol on ozone depleting substances. Similarly, the CILSS (Comité permanent Inter-Etats de Lutte contre la Sécheresse), a regional organisation fighting desertification, could support efforts in the field of sustainable forest management for cooking fuels. Finally, on-going negotiations on a convention to control mercury pollution could finance efforts to capture emissions from coal-fired power stations, as well as for the recycling of mercury containing light bulbs.

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[4] Given the nature of West African power systems, notably the large distances covered by lines and the low population density, it is considered that a reasonable goal is to reduce losses to 10%.

[5] It is perhaps useful to recall, that although LPG is a fossil fuel, cooking with LPG emits less Green House Gases than poorly burned wood. Indeed, poorly burned wood emits both CO_2 and large quantities of powerful GHGs such as methane and NO_2, as well as black carbon. A typical meal cooked on a 3 stone fire emits over 800 g CO_2 equiv of GHG, of which over half is in non CO_2 GHGs, as compared to less that 200 g CO_2 equiv for a meal cooked with LPG [5].

Conclusion

The Energy Efficiency Policy, including the five initiatives, was adopted by the ECOWAS Energy Ministers at their meeting in Accra from 29 to 31 October 2012. This meeting was organised in parallel with a "Global Forum on Sustainable Energy[6]" meeting on the theme "Towards Sustainable Energy For All in West Africa: Paving the Way through Renewable Energy and Energy Efficiency". Representatives of the international community, private sector and civil society, participated along with the region's public authorities in discussion on the contribution of energy efficiency and renewable energy to meet the challenge of achieving universal access to energy in West Africa.

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[5] http://www.scribd.com/doc/31339153/Cooking-in-Developing-Countries-Fuel-Consumption-and-GHG-Emissions-User-Acceptance

[6] The Global Forum on Sustainable Energy is a biannual event, usually taking place in Austria, around the themes of sustainable energy and development.

Maximizing Climate Benefits through Energy Efficiency and Refrigerant Regulations for Air Conditioners: A case from India

Amit Khare, Ana Maria Carreño

Collaborative Labeling and Appliance Standards Program (CLASP)

Abstract

The ownership and usage of room Air Conditioners (ACs) in India is increasing rapidly mainly due to a growing economy and a high number of cooling days per year. Today air conditioning accounts for a significant share of peak electricity demand during the summer months in many Indian cities. In response to growing AC usage, the Indian Bureau of Energy Efficiency (BEE) launched a voluntary energy efficiency labeling program for room ACs in 2006, which became mandatory in 2010.

Most ACs globally use hydrochlorofluorocarbons (HCFCs), ozone depleting substances expected to be phased-out in developed countries by 2020 and in developing countries by 2030, per the Montreal Protocol. Hydrofluorocarbons (HFCs), commercially available alternatives to HCFCs, do not deplete the ozone layer but are potent greenhouse gases. If all the AC manufacturers in India switch over to HFCs the greenhouse gas (GHG) emissions would increase by at least 15%[1]. If HCFCs could be cost effectively replaced by "climate friendly refrigerants" such as natural refrigerants instead of HFCs, the climate benefits of the HCFC phase-out would be maximized.

This paper develops three policy scenarios for room ACs in India analyzing their impact in terms of GHG emissions reductions due to electricity savings and usage of climate friendly refrigerants, and its cost-effectiveness. The scenarios examine a business as usual approach, using current and planned efficiency standards for room ACs, and additional climate benefits by introducing the requirements for the mandatory use of climate friendly refrigerants. GHG emissions savings are estimated using the methodology provided by the Total Equivalent Warming Impact (TEWI) indicator. The paper identifies the scenario that will result in maximum reduction of GHG emissions and still be cost-effective if adopted, which corresponds to a policy scenario of doubling the current pace of efficiency increases and requiring the use of refrigerants with low Global Warming Potential (GWP < 150) in 2016.

Introduction

The ownership and usage of Room Air Conditioners (ACs) in India is increasing rapidly mainly due to a growing economy and a high number of cooling days per year. The AC industry estimates sales of 3.5 million new units in 2012 and forecasts sales in 2020 and 2030 of more than 12 million and 40 million units respectively [1].

BEE's labeling program for room ACs has resulted in savings over 5000 MW [2] and related greenhouse gas (GHG) emissions reductions so far, but the standards do not include any requirements to use climate-friendly refrigerants to further lower overall GHG emissions. Adding such requirements would help India in achieving its commitment of cost-effectively reducing emissions per unit of GDP by 20 to 25 percent below 2005 levels by 2020 [3].

This paper develops three policy scenarios for energy efficient room ACs in India, analyzing their impacts in-terms of GHG emissions reductions due to electricity savings and usage of climate friendly refrigerants, and its cost-effectiveness. This approach is expected to serve as a foundation for designing future policies to maximize climate benefits considering not only the emissions derived from energy use but also climate impacts from refrigerants. Finally, the results will be presented to BEE and the Ozone Cell[2] in India for their consideration prior to the launch of the next revision of AC energy efficiency standards in 2014.

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[1] Estimated from the rate of GWP_{HFC}/GWP_{HCFC}

[2] The Indian Ministry of Environment and Forests has set up Ozone Cell in India for the work related to protection of ozone layer and implementation of the Montreal Protocol

The Residential Room Air Conditioners market in India

The current market in India is divided between two types of room ACs: window units and split units. Their rated cooling capacity is usually up to 11 kW. In 2012, window ACs sales were nearly 25% of the total market, down from 50% of the market in 2007, showing the increased popularity of split ACs over the past years[3]. Nonetheless, sales of the two air conditioner types in India grew steadily from 2007 to 2011, as can be seen in Figure 1, with a drop in 2011-12 possibly due to a cooler summer and an early arrival of the monsoons. Larger sales in the previous period, 2010-11, might have also negatively affected sales the following year. This is thought to be the result of a bonus offered by the Indian Government to federal employees, which translated in higher purchases of appliances for that period.

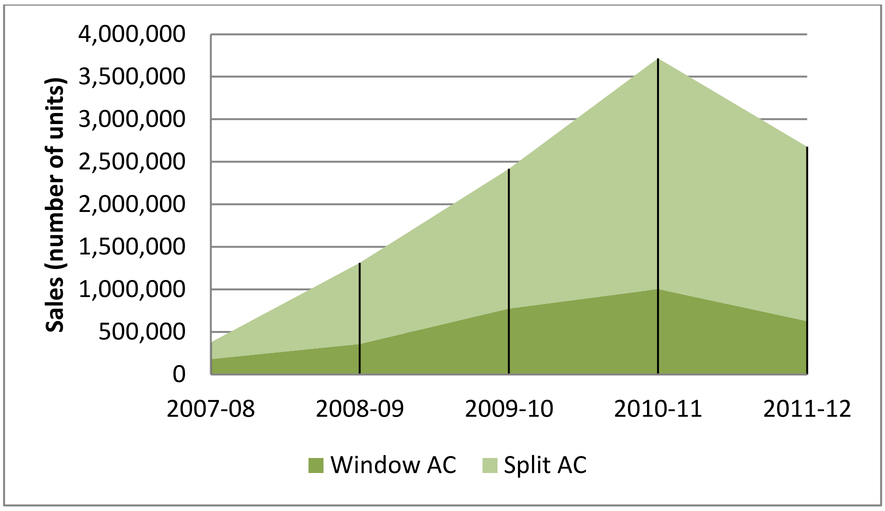

Figure 1: Room Air Conditioner Sales in India (2007-2012)

Over the five year period in Figure 1, sales of window air conditioners more than tripled, from over 180,000 units in 2007-08[4] to 626,000 units in 2011-12. Sales of split air conditioners increased more rapidly; for the same period, sales in 2011-12 were ten times more than those in 2007-08 (from 195,000 to more than 2,000,000).

At a global level, sales of ACs in India are still significantly lower than countries like Japan and the United States which have annual sales of more than 6 million and 9 million units respectively, and economies like China, and Brazil which are expected to reach similar market sizes in the coming years. The room ACs market (for the residential sector) is dominated by split units worldwide; inverter units[5] are available in developed economies and their popularity is increasing among developing economies [4]. The market in India is still dominated by fixed-speed units.

However, India's annual sales of ACs are expected to increase dramatically in the next 20 years. Ownership of ACs in India is estimated to be between 4 – 5%[6]. The market penetration potential is still very large and thus growth in the coming years is only expected to rise. Sales forecasts in 2020 and 2030 are of more than 12 million and 40 million units respectively, corresponding to a 13% increase per year [5].

The Standards and Labeling program for ACs in India

The standards and labeling (S&L) program in India was initiated in 2006 as a response to growing energy demand by refrigerators and air conditioners. The energy performance standard for room ACs applies to single-phase split and unitary (window) air conditioners of the vapor compression type for household use up to a rated cooling capacity of 11 kW being manufactured, imported or sold in India

[3] Sales data from BEE records: *Production Data: Financial Year: 2007-08, 2008-09, 2009-10, 2010-11, 2011-12.*
[4] BEE's production data over the financial year period covers April 1st Year X to March 31st Year X+1.
[5] Units with variable-speed drives
[6] Population: 1.2 billion; average household size: 4 – 5 people; access to electricity: 60 – 65%; Stock in 2011 ~ 8 million units.

[6]. Energy efficiency is rated by the number of stars displayed in the energy label, between a minimum of one and a maximum of five.

Comparative labeling requirements for room ACs were voluntary until 2010; from the period between January 7, 2010 to December 31, 2011 the mandatory minimum energy performance standard (MEPS) for room ACs under this regulation was of EER[7] (W/W) 2.3. The next update occurred in January 1, 2012 when the minimum EER became 2.5. An additional scheduled update will take place in January 1, 2014, as per Table 1 below.

Table 1: Energy Performance Standard for Room ACs in India

	07 January 2010 to 31 December 2011		01 January 2012 to 31 December 2013		01 January 2014 to 31 December 2015	
	EER(W/W)		EER(W/W)		EER(W/W)	
Star Rating	Min.	Max.	Min.	Max.	Min.	Max.
1 star	2.3	2.49	2.5	2.69	2.7	2.89
2 star	2.5	2.69	2.7	2.89	2.9	3.09
3 star	2.7	2.89	2.9	3.09	3.1	3.29
4 star	2.9	3.09	3.1	3.29	3.3	3.49
5 star	3.1		3.3		3.5	

The schedule above requires an increase in the minimum efficiency level of 8% each 2-year period until 2015.

Room ACs efficiency levels and other parameters

Today, air conditioning accounts for a significant share of peak electricity demand during the summer months in many Indian cities [7]. BEE's labeling program aims to reduce ACs energy demand and there is actually a slow shift to more efficient units since the program began.

The average Energy Efficiency Ratio (EER) values for both split and window units increased over time, as shown in Figure 2, illustrating the shift to more efficient units. The average efficiency of split ACs increased 27% (or an average of 4% per year) from 2.30 in 2006 to 2.91 in 2012. The average efficiency of window units has increased at a slower pace of 17% over the same period (or 3% per year), from 2.30 in 2006 to 2.68 in 2012.

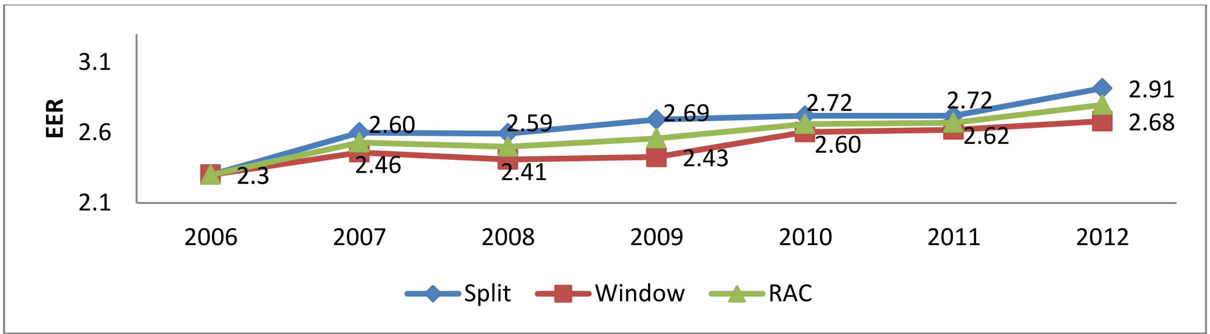

Figure 2: Average EER of Room ACs in India

Interestingly, the increase rate displayed by the market average EER levels from 2006 to 2012 in Figure 2 above (an increase of 4% per year) corresponds to the increase required by BEE on the minimum efficiency level of 8% each 2-year period. One could argue that BEE's program is driving the market towards higher efficiency levels and the market's response is closely linked to the level of standards required. It could also be the other way around, and observations of the market behavior

[7] Energy Efficiency Ratio (EER) is the ratio of the cooling capacity to the electricity consumption when measured at full load at a specific outdoor temperature (usually 95 degree Fahrenheit).

before the introduction of the labeling program drove BEE to choose a policy that reflected this trend. The average EER level of Room ACs on the market in any year (during the period 2010-2012) was on average 0.3 units above the minimum EER of that year (this is 16% better than the minimum energy performance standard – MEPS - in 2010 or 12% better than the MEPS in 2012).

The labeling program requires that products on the market are rated using a scale from 1 star (least efficient) to 5 stars (most efficient). Figure 3 and Figure 4 show the trends of room ACs sales according to their efficiency level over a five year period. Split air conditioners in star level 5, the most efficient level, had a 25% market share for the first time in 2012. However, star levels 2 and 3 remain very popular as shown in Figure 3. For window ACs, the more efficient levels (5 and 4) still have a very low market share (see Figure 4), an indication that the production of more efficient window AC units is not taking place under current market conditions[8]. This is a trend also present in other countries: while the market share of window ACs is decreasing globally, efficiency levels have remained the same or even decreased over the past years [4]. In Europe, for instance, the market share of window units stagnated since 2005 at 200,000 units per year; the average EER level reached a maximum of 2.9 in 2005 and then decreased to 2.7 in 2011.

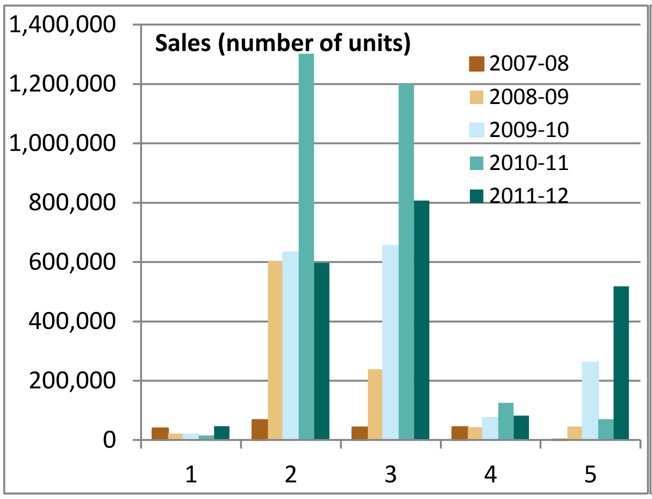

Figure 3: Efficiency levels of split ACs sales [4]

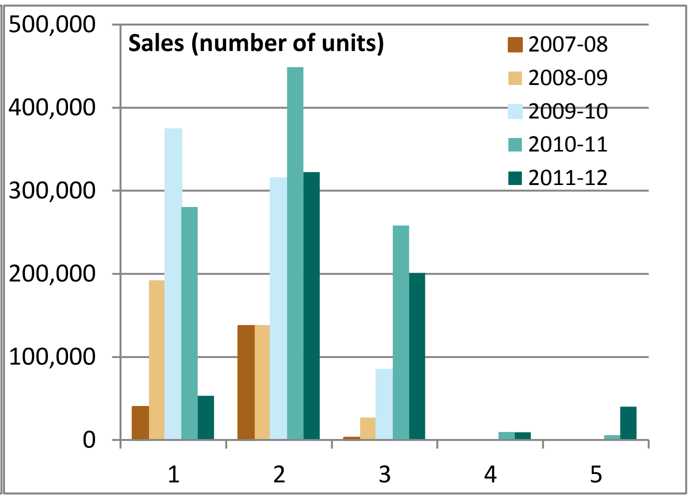

Figure 4: Efficiency levels of window ACs sales [4]

Another relevant parameter to characterize room ACs is the size (cooling capacity). The most recent available data (from 2009) indicates that rooms ACs below 3kW have minor market shares in both types (window and split units).

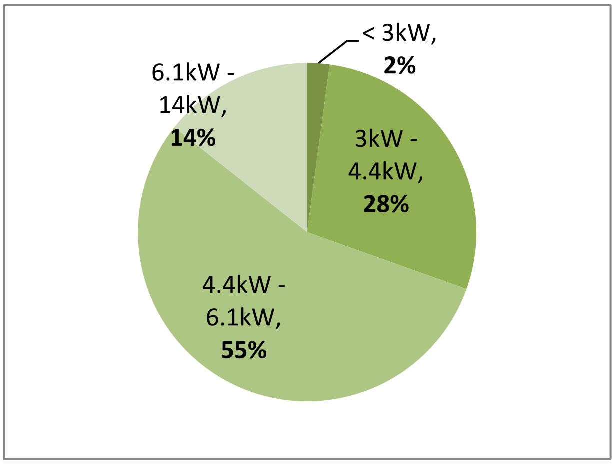

Figure 5: Sales of split units by size, 2009 [4]

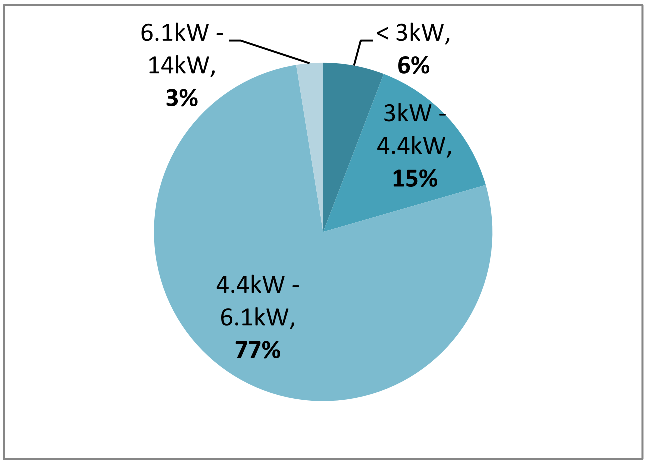

Figure 6: Sales of window units by size, 2009 [4]

[8] Manufacturers' feedback is that due to technology constraints it becomes very costly to produce 4 and 5 star window ACs.

The most popular sizes are 4.4kW to 6.1kW, followed by 3.0 to 4.4kW. Window units over 6.1kW are not very common, while split ACs from 6.1 to 14kW accounted for 14% of the split AC market in 2009. Figure 5 and Figure 6 above show market shares of various sizes by type of AC [4].

Refrigerants in ACs

Most ACs globally use fluorocarbon refrigerants to facilitate the heat transfer process; hydrochlorofluorocarbons (HCFCs) are among those commonly used in air conditioning applications and have been used as transitional substitutes for the now phased-out chlorofluorocarbons (CFCs) for a host of applications. In 2007, the Parties to the Montreal Protocol decided to accelerate the phase-out of HCFCs. The Decision also encourages Parties to maximize other environmental benefits of the HCFC phase out, including those related to climate change.

HCFCs are scheduled to be totally phased out in developed countries by 2020 and in developing countries by 2030. Non-ozone depleting hydrofluorocarbons (HFCs) are commercially available alternatives to HCFCs; annual consumption of HFCs has doubled over the last decade. While they do not deplete the ozone layer, they are potent greenhouse gases and are about 2,000 times more powerful in trapping heat in the atmosphere than carbon dioxide. If HCFCs could be replaced by “climate friendly refrigerants” such as natural refrigerants (hydrocarbons, carbon dioxide, ammonia) and/or by new very low-GWP hydrofluoroolefins (HFOs, e.g. HFO-1234yf, HFO-1234ze, etc.) cost effectively, then the climate benefits of the HCFC phase-out could be maximized.

HCFC-22 (R-22) is still the most commonly-used refrigerant in ACs in developing countries, with an Ozone Depleting Potential (ODP) of 0.055 and a Global Warming Potential (GWP) of 1,810 [8]. Developed countries are transitioning to HFC-410A (R-410A), with zero ODP but a GWP of 2,088, which can adversely impact the climate due to its large capacity as greenhouse gas. Some of the alternatives considered for transitioning to lower GWP refrigerants in room ACs, which pose a lower burden to the global climate, include carbon dioxide (R-744), propane (R-290), HFC-32 (R-32), and HFO blends.

Table 2 shows, in a very simplified manner, technical characteristics and economic considerations for various refrigerants and how they ranked in comparison to others. This is only indicative and aims to highlight the potential challenges of a transition to any of those alternative refrigerants.

Table 2: Technical characteristics and economic considerations for some refrigerants[9]

	GWP	Flammability	Toxicity	Price of Refrigerants	Price of System	Volumetric Refrigeration Capacity	Theoretical System Efficiency
Hydrofluoro-carbons (HFCs)	High	No	No	Moderate	Low	Medium	Good
Hydrocarbons (HCs)	Low	Yes	No	Low	Medium	Medium	Good
Carbon Dioxide	Low	No	Only at high concentration	Low	Medium	High	Medium

Table 2 shows that a transition to hydrocarbons or carbon dioxide as AC refrigerants will increase equipment cost, as the price of the refrigeration system for these refrigerants is higher than that of HFCs. There are impacts on efficiency, especially in the case of carbon dioxide, and flammability issues linked to the use of hydrocarbons. Even though the use of these alternatives poses technical challenges, leading AC manufacturers are proving the feasibility of this transition. In China, Gree announced the completion of a demonstration production line for split ACs using R-290, while Midea is ready to commercialize products also using R-290 [1]. In India, one of the domestic appliance manufacturers “Godrej” has started production of R-290 based split ACs system with energy efficiency ratio close to 3.7 (i.e. 6% better than the 5 star level of the 2014-15 standard).

[9] Author’s interpretation from Kauffeld, 2011. [12]

Assessing the impacts of a transition to climate friendly refrigerants in India

BEE's labeling program for room ACs has resulted in savings over 5000 MW [2] and related GHG emissions reductions, but the standards do not include any requirements to use climate friendly refrigerants to further lower overall GHG emissions. Adding such requirements would help India achieve its voluntary commitment of cost-effectively reducing emissions per unit of GDP by 20 to 25 percent below 2005 levels by 2020 [3].

To examine the impacts of a transition to lower GWP refrigerants, this paper develops three policy scenarios for room ACs in India:

- **Base case**: Energy efficiency requirements for room ACs after 2015 continue to increase by 8% every two years to reach a minimum efficiency level EER = 3.3 in 2020. This is consistent with the previous schedule adopted by BEE, where efficiency increases 8% in two-year intervals. There are no requirements for the GWP of refrigerants used in Room ACs in this scenario.

- **Policy option 1**: BEE adopts a schedule that will reach the minimum efficiency levels of the current best available technology in the Korean market[10], EER = 5.7[11], in 2020. There are no requirements for the GWP of refrigerants used in room ACs in this scenario.

- **Policy option 2**: BEE adopts a schedule that will increase the minimum efficiency levels to an EER = 4.2 in 2020. This is the result of doubling the current pace of efficiency increases, from 8% every two years to 16%. In addition, this policy option requires the use of refrigerants with GWP < 150[12] in 2016.

- **Policy option 3**: Policy option 1 and requires the use of refrigerants with GWP < 150 in 2016.

Table 3: Summary of policy scenarios

	Minimum Efficiency levels in EER			
	Base case	**Policy 1**	**Policy 2**	**Policy 3**
2010	2.3	2.3	2.3	2.3
2011	2.3	2.3	2.3	2.3
2012	2.5	2.5	2.5	2.5
2013	2.5	2.5	2.5	2.5
2014	2.7	2.7	2.7	2.7
2015	2.7	2.7	2.7	2.7
2016	2.9	3.7	3.1	3.7
2017	2.9	3.7	3.1	3.7
2018	3.1	4.7	3.6	4.7
2019	3.1	4.7	3.6	4.7
2020	3.3	5.7	4.2	5.7
GWP < 150 starting in 2016	No	No	Yes	Yes

For the three policy options, we analyze energy savings and GHG emissions reductions from the base case by forecasting energy use of ACs sold from 2012 to 2020 and 2030. We assume that every unit

[10] The market in India is dominated by Korean and Japanese manufacturers.
[11] Maximum EER reported in Korea in 2010-2011 [13]
[12] Two regulations in the EU currently use this threshold (GWP<150): i) Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases, exempts preparations where the total global warming potential is less than 150, and ii) Commission Regulation (EU) No 206/2012 of 6 March 2012 with regard to ecodesign requirements for air conditioners and comfort fans, requires different (less stringent) minimum energy efficiencies for appliances if GWP of refrigerant ≤ 150.

sold in a specific year has an EER equal to the minimum energy performance requirement as per Table 3 above. This means we do not estimate additional energy savings from the labeling program. This is a conservative approach given that the labeling program has effectively shifted the market towards higher efficiency levels (on average 0.3 units above the minimum EER level for any specific year) as discussed earlier.

We also consider that the stock has a survival function based on a normal distribution of the median life of ACs (10 years) and a sales growth of 13% per year. Figure 7 shows the sales forecast per year, the portion of the stock (from those annual sales) that survives in 2030 and the portion that has been retired[13].

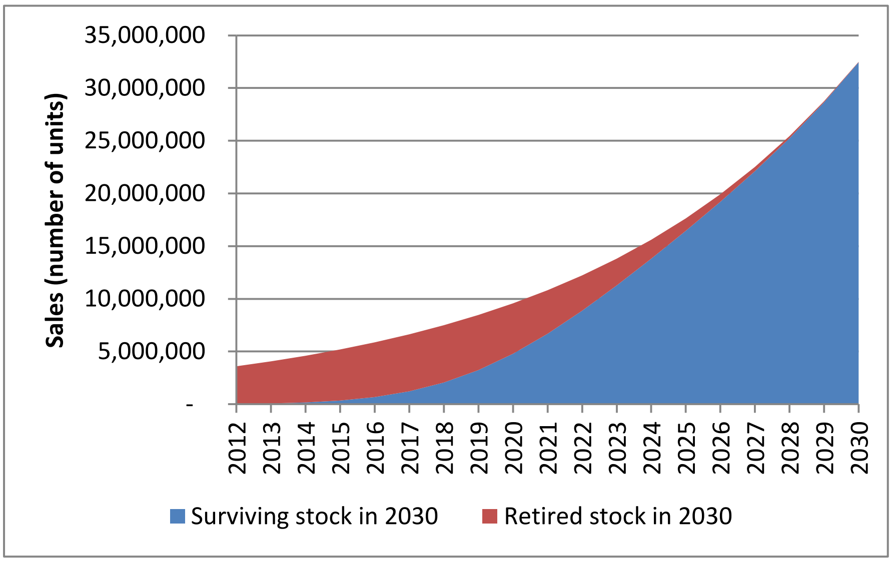

Figure 7: Room ACs sales forecast 2012 – 2030

The Total Equivalent Warming Impact (TEWI), an indicator used to estimate the global warming impact of room ACs (and other equipment using refrigerants), is based on the emissions of greenhouse gases during the operation (use) and the disposal of the refrigerants at the end-of-life [9]. The method of calculating the TEWI is the following:

TEWI = GWP (**direct** *emissions from refrigerant leaks and end of life treatment*) + GWP (**indirect** *emissions from the operation of the equipment*)[14]

Indirect emissions

Indirect emissions, corresponding to GHG emissions resulting from the operation of room ACs throughout their lifetime, were estimated as follows.

The room AC unit energy consumption (UEC) is estimated for a typical 1.5T unit [10], considered representative of the AC market, with the following parameters[15]:

Hours of operation (residential): 5 months/year x 30days/month x 8hrs/day = 1200hrs/year[16]

Average cooling capacity (CC): 4,580 kW

Operating at 75% of full capacity

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[13] Surviving stock in 2030 refers to the number of units purchased in a year X that are still operating in 2030. Retired stock refers to the units that are no longer operating due to failure.
[14] The terms direct and indirect emissions used here are as per the TEWI method of calculation best practice guidelines [9]
[15] The typical unit size and operation conditions are as per McNeil and Iyer.
[16] As per BEE's assumption when calculating ACs labeling program impacts (energy consumption and savings).

$$UEC(y) = \frac{CC}{EER(y)} \times 0.75 \times 1200 \quad (kWh/y)$$

The Total Energy Consumption (TEC) in a year is estimated with the surviving stock in that year and the corresponding unit energy consumption. The following equation uses 2030 as the year for the calculations.

$$TEC_{\ 2030} = \sum_{y=2012}^{2030} Surviving\ stock\ in\ 2030\ (y) \times UEC\ (y) \qquad (kWh/y)$$

GHG emissions savings are estimated with the total energy consumption and an emissions factor of 0.82 tonnes of CO2 eq per MWh [11].

$$GHG\ savings\ in\ 2030 = TEC_{2030} \times 0.82 \quad (tCO2e)$$

Results from the analysis above are presented in Table 4 for 2020 and 2030.

Table 4: Energy and GHG emissions savings due to ACs operation from policy scenarios

	Base case	Policy Option 1	Policy Option 2	Policy Option 3
Total energy consumption in 2020 (GWh)	73,739	57,786	67,133	57,786
Total energy savings in 2020 (GWh)	-	15,953	6,606	15,953
GHG savings in 2020 (Mtonnes of CO2 eq)	-	13.1	5.4	13.1
Total energy consumption in 2030 (GWh)	247,406	133,791	195,528	133,791
Total energy savings in 2030 (GWh)	-	113,615	51,878	113,615
GHG savings in 2030 (Mtonnes of CO2 eq)	-	93.2	42.5	93.2

Direct emissions

To analyze the climate benefits of introducing a requirement for the use of refrigerants with lower GWP, emissions of greenhouse gases from the refrigerants need to be considered.

In the previous section we estimated the GHG emissions from the operation of ACs (indirect emissions) and provided a total GHG savings in 2020 and 2030; in this section we will only consider the first part of the TEWI equation to estimate emissions from the refrigerants.

$$GWPdirect = GWP \times m \times L_{annual} \times n + GWP \times m \times (1 - \alpha_{recovery})$$

Where:

GWP = Global Warming Potential of the refrigerant
m = refrigerant charge
L_{annual} = leakage rate per annum
n = operating life
$\alpha_{recovery}$ = recycling factor from 0 to 1

The recycling factor in India is considered to be 0, thus we assume that all the refrigerant charge will be released at the end-of-life[17] (disposal of the AC), and only estimate the right side of the equation. For the analysis, two parameters are considered: the refrigerant charge and the GWP.

The typical refrigerant charge of AC units relevant to the Indian market is shown in Table 5 and the GWP values for current and alternative refrigerants are shown in Table 6.

Table 5: Typical refrigerant charges in ACs[18]

		Average charge (kg)			
Unit	**Capacity**	**R-410A**	**R-22**	**R-32**	**R-290**
Mini-split	1.5 T	1.5	1.2	1.3	0.4

Table 6: GWP values for selected refrigerants [8]

Refrigerant	GWP
R-410A	2088
R-22	1810
R-407C	1774
HFO Blends	<1,032
R-32	675
R-1234ze	6
R-1234yf	4
R-290 (propane)	3.3
R-744 (CO2)	1

For the policy options (Base Case and Policy Option 1) for which there is no requirement to transition to lower GWP refrigerants, we consider a GWP that corresponds to that of R-22 until 2020 (as scheduled by the Montreal Protocol) and is replaced by R-410A from 2020 (which is the current trend). For the policy options where a refrigerant requirement will be in place in 2016, we consider the GWP of R-22 until 2015, and the propane GWP of 3.3 from then onwards. The refrigerant charge varies depending on the refrigerant as per Table 5.

Table 7: Summary of policy scenarios in the transition to lower GWP refrigerants

	GWP values			
	Base case	**Policy 1**	**Policy 2**	**Policy 3**
2012-2015	1810	1810	1810	1810
2016-2019	1810	1810	3.3	3.3
2020-2030	2088	2088	3.3	3.3

Using the retired stock of ACs from 2012 – 2030, and the corresponding *GWPdirect*, we estimate the cumulative value of greenhouse gas emissions by 2030 from their refrigerants charge as:

$$Cumulative\ GHG_{2030} = \sum_{y=2012}^{2030} Retired\ stock\ in\ 2030\ (y) \times GWPdirect\ (y)$$

The same calculation is done for the year 2020 using the retired stock from 2012- 2020. Results from the analysis above are presented in Table 8.

[17] If a recycling program for ACs were in place, the recovery rate will be > 0. There are no recycling or recovery policies as of today in India.
[18] Based on discussion with key AC and chemical manufacturers in India

Table 8: GHG emissions savings from the transition to lower GWP refrigerants

	Base case	Policy Option 1	Policy Option 2	Policy Option 3
Cumulative GHG emissions by 2020 (Mtonnes of CO2 eq)	7	7	6	6
Cumulative GHG savings by 2020 (Mtonnes of CO2 eq)	-	-	1	1
Cumulative GHG emissions by 2030 (Mtonnes of CO2 eq)	143	143	37	37
Cumulative GHG savings by 2030 (Mtonnes of CO2 eq)	-	-	106	106

Cost considerations and feasibility analysis

Technology options for improving efficiency of ACs

Typically, the options for improving the energy efficiency of ACs focus on changes in the following components:

- Compressor
- Heat exchanger
- Fan motor

Both efficiency and cost implications associated with improvements in these components largely vary from manufacturer to manufacturer and are based on overall system design.

Improvements in compressor: The two major types of compressors used in ACs are rotary and scroll compressors. Rotary compressors are manufactured locally in India and are also imported. At present rotary compressors with an EER of 3.6 are already being used by some Indian manufacturers. According to compressor suppliers, both 1st stage and 2nd stage rotary compressors can achieve a gain of 0.2 units in the EER. However the incremental costs associated with 1st stage and 2nd stage rotary compressors are 10% and 20% respectively, over base case.

Scroll compressors are 15-20% more efficient than rotary compressors but they are not manufactured locally in India. A USD 20 increase in manufacturing cost is likely with the use of scroll compressor over rotary compressor.

Improvements in heat exchanger: Currently manufactured ACs use copper tube aluminum fin CTAF technology for heat exchangers. But new technologies like Brazed Aluminium Micro Channel (BAM) can achieve same efficiency with 25-30% less area and thus reduce costs of achieving higher efficiency in ACs. A few manufacturers in India are importing BAM heat exchangers but its applicability for RACs is yet to be established.

Improved fan motors: Brush Less DC (BLDC) fan motors are 50% more efficient than the conventional AC motors. However the cost difference between the two types of AC motors is substantial. Each unit of BLDC fan motor costs approx. USD 40 compared to USD 6-8 for an AC fan motor. Besides, BLDC fan motors are not locally manufactured and have to be imported.

Efficiency, cost and feasibility considerations under policy scenarios

Under policy option 1, minimum efficiency levels for ACs would increase to an EER of 5.7 by 2020 from the base case EER of 3.3. This 70% improvement in minimum efficiency levels can be achieved by incorporation of BLDC fan motors that lead to 50 to 60% improvement in energy efficiency compared to AC fan motors uses in currently manufactured ACs in India. However, use of BLDC fan motor will increase the manufacturing cost by 5 times. Besides, manufacturers will have to rely on importing this technology as there are limited numbers of BLDC fan motor suppliers in India. However, production of BLDC fan motors in India will lead to cost-effective improvements in energy efficiency.

Under policy option 2, BEE adopts a schedule that increases the minimum efficiency levels to an EER of 4.2 in 2020 and also requires the use of refrigerants with GWP < 150 by 2016. In India, a leading AC manufacturer has recently produced an AC which has a GWP < 150 and an EER of 3.7. Further increase in EER from 3.7 to 4.2 can be achieved by using a combination of improved compressor technology like scroll compressor and use of BLDC fan motors.

The use of climate friendly refrigerants with GWP < 150 will lead to substantial reductions in CO_2 emissions over the life of the AC. An Indian manufacturer is already producing R-290 (GWP < 20) based ACs. It has been found that the cost of R-290 is more than that of conventional HFC refrigerants like R-410a in the current scenario. However, if adopted on a large scale, the cost will drastically come down due to economies of scale and will be at part with the conventional refrigerants. Propane is also a byproduct of some of the industries in India, although in impure form. If AC industry starts using propane by extracting the pure chemical from the byproduct, the cost can come down significantly. The application of propane is limited currently because of safety concerns due to its flammable nature.

Under policy option 3, BEE adopts policy option 1 and requires the use of refrigerants with GWP < 150 in 2016. This can be achieved by using the measures identified under policy option 1 and option 2.

Summary of Results

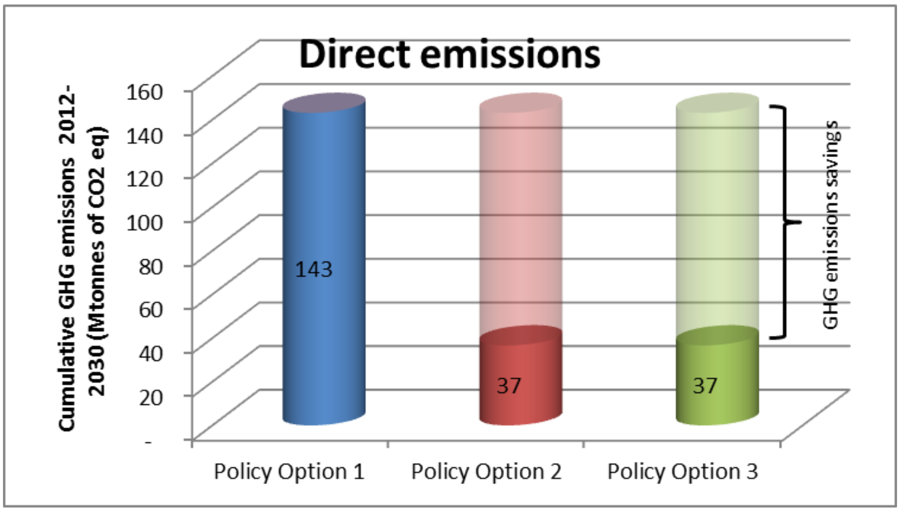

Figure 8: Direct emissions – cumulative GHG emissions from 2012 - 2030

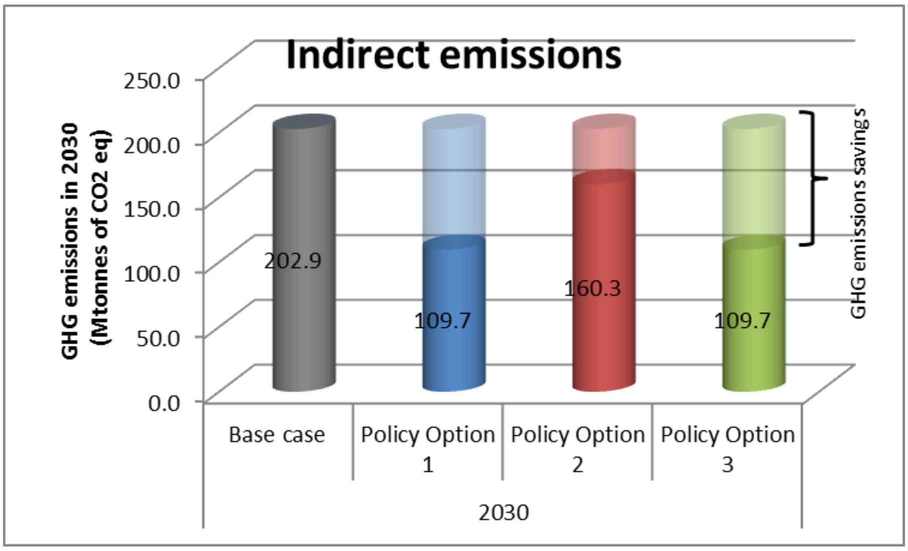

Figure 9: Indirect emissions – Annual GHG emission in 2030

Conclusions

Including the use of climate friendly refrigerants as part of the energy efficiency requirements for room ACs can have a great impact on the long term emissions from this equipment. This analysis showed that in 2020 (only 4 years after the proposed implementation date of 2016) the savings are not significant since the retired appliances over that period are very few. However, there are considerable savings from the transition to lower GWP refrigerants in the long term. If implemented, the cumulative savings from direct emissions by 2030 (106 Mtonnes of CO2 eq.) could be nearly 75% of the cumulative emissions (143 Mtonnes of CO2 eq.) of the base case (if no policy was implemented).

From the energy savings point of view, policy options 1 and 3 result in total energy savings of 113,615 GWh in 2030 (and corresponding GHG emissions mitigation = 93.2 Mtonnes of CO2 eq.). Policy option 3 offers additional GHG emissions savings from direct emissions (106 Mtonnes of CO2 eq. cumulative by 2030). However, in the context of an emerging market, adopting the measures to increase the energy efficiency of ACs by 70% in a time frame of 6 years with the use of climate friendly refrigerants (GWP<150) would be quite challenging and costly. It could increase the price of the retail product significantly, making efficient ACs out of reach for an average consumer. Policy option 1 presents the same challenges as option 3 in terms of increasing AC efficiency (without the additional cost of transitioning to low GWP refrigerants) and it offers the least GHG mitigation potential; hence it is not the recommended policy option.

Policy option 2 is the most suited option for the Indian scenario: it is a cost effective option (one of the Indian manufacturer has already started the production of such units) and has significant impact in terms of GHG emissions reduction. It results in GHG emissions savings of over 93.2 Mtonnes of CO2 eq. per year after 2030 (from indirect emissions) and additional cumulative savings of 106 Mtonnes of CO2 eq by 2030 (from direct emissions).

Therefore, this paper identifies policy option 2 as the recommended option for future AC regulations in India. It also recognizes implementation challenges since it would require enhanced coordination and communications between two agencies, BEE and Ozone Cell, which until now regulate energy efficiency and consumption of refrigerants in India independently. However, if these challenges could be addressed, India's ACs policy would result in long term sustainability through significant GHG emissions reduction from energy savings and the use of climate friendly refrigerants.

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The Turkish Energy Efficiency Plan – an ex-ante assessment of the residential sector

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Abstract

The aim of this study is to analyse the impact of the Strategic Energy-Efficiency Plan (SEEP) on residential energy demand in Turkey until 2030. For this purpose, three different explorative scenarios have been developed: a reference scenario (REF-S); a scenario based on the SEEP (SEEP-S) and a scenario which includes even more ambitious policies (HiEff-S). The scenarios are being compared in terms of energy demand and allow conclusions about the potential impact of the policy packages. For the analysis, a detailed bottom-up modelling approach is applied. The results show that the final energy demand decreases in all scenarios from about 944 PJ in 2008 to 851 PJ (REF-S), 736 PJ (SEEP-S) and 659 PJ (HiEff-S) in 2030. The decreasing demand even in the REF-S reflects a structural break with the past and mainly comes from the building sector and is driven by a very high demolition rate and a very low level of efficiency in the existing building stock. This drastic policy induces a fast building turnover, which is a window of opportunity from an energy efficiency point of view – which, however, is not taken into account by current legislation and not particularly addressed in the SEEP. Both the share of electricity but also the total demand in all scenarios is increasing – mainly driven by the growing ownership of various electric appliances. The SEEP-S will achieve 10 TWh of savings in 2030 compared to the REF-S which mainly comes from more ambitious appliance and lighting standards. Generally, the scenarios assumed a relatively high rate of compliance and a strong enforcement of policies, which might not be the case in reality (as already indicated by the observed slow progress of building certification by 2013 which is running far behind schedule).

Introduction

In recent years, Turkey has become one of the largest emerging markets in the world with high economic growth and a relatively young as well as fast-growing population. In 2010 GDP rose by 9 % and GDP per capita has tripled since 2002 (after the financial crisis in 2001), reaching 10,500 US$ in 2010 [1]. In the same year, Turkey's population reached the level of 74.7 million compared to 56.5 million in 1990. As a result, Turkey has become the sixth biggest economy in Europe [2, 3]. As could be witnessed in the past, economic growth came together with an increase in energy demand. Final energy demand increased by approximately 4 % per annum between the years 2009 and 2011, while growth of electricity demand has been even higher, 4.7 % per annum for the same years and expected to rise [23]. This dynamic development induces high pressure on the Turkish energy system, as Turkey depends on foreign resources for 72 % of its demand in 2010 [43].

In 2012 the Turkish government developed the strategic energy efficiency plan (SEEP) to cope with the increasing demand [34]. The plan sets targets for the coming ten years until 2023 and requires policies to be implemented in all demand sectors, such as market transformation of energy-using products (following the EU Eco-design Directive [27, 28]) or energy usage in buildings [18, 19]. To reach the goals defined in the SEEP, i.e. improving energy efficiency in the residential sector, plays a significant role. In 2010, 35% of final energy demand in Turkey was attributed to the residential sector and the importance of this sector is expected to grow even more. Not only because of its high percentage share in final energy demand, but also due to rising living standards, decreasing average size of households and as a result of an increasing demand for new buildings due to high urbanization rates [4].

The aim of this study is to analyse the impact of the SEEP on residential energy demand in Turkey until 2030 based on three explorative scenarios. The reference scenario (REF-S) is used as a baseline, the scenario SEEP-S simulates the impact of the SEEP policies, and the scenario HiEff-S includes even more ambitious policies than the SEEP requires. For the analysis the bottom-up model, FORECAST-Residential is applied that uses empirical data such as the ownership rate of appliances, the building typology or the efficiency development of heating systems to determine final energy demand projections [5, 6]. The explicit consideration of individual end-uses allows a very detailed modelling of the individual policy measures defined in the SEEP. Besides techno-economic parameters and socio-economic parameters, such as the number of households, are also taken into account in the simulation. Thus, the main determinants of Turkish energy demand are considered in this approach.

Status quo of energy-efficiency policies for the residential sector in Turkey

In the last decades, Turkey has reacted to the expanding energy demand with increasing the import of fossil fuels. As a result, Turkey has become more import-dependent and CO_2 emissions have increased drastically. However, a significant share of energy demand could have been avoided by reducing the energy losses in production, transportation/distribution and final demand by lowering the need for fossil fuel use and import. This point of view has become more central in recent years in Turkey and a mix of energy-efficiency policies has been implemented, of which several measures address the residential sector.

Laws and regulations in force

The legal framework and its key laws and regulations that aim to improve energy efficiency in the residential sector in Turkey are summarized in Table 1.

Table 1: Overview of regulations addressing energy efficiency in the residential sector in Turkey

Law / regulation	**Aim and scope with regard to residential sector**	**Implementation (latest revision)**
Laws and regulations addressing residential buildings		
Energy Efficiency Law (no. 5627) [15]	A broad frame for energy-efficiency policies in all sectors and the implementation of more specific regulations.	2007
Energy Efficiency Regulation [16, 17]	Authorization and standards for ESCOs including training curricula for energy managers, public entities energy efficiency programs.	2008 (revised 2011)
Building Energy Performance Regulation [18, 19]	Setting minimum energy performance standards (MEPS) for buildings, regulation of MEPS calculation, use of renewable energies and HVAC systems.	2008 (superseded Reg. on Heat Insulation in 2009, revised 2010)
Regulation on Heat Insulation in Buildings [20, 21]	Requirements for thermal performance of building insulation.	2000 (superseded in 2009)
National Standard of Thermal Insulation Requirements for Buildings (TS 825) [22]	Calculation procedures for standards for building insulation.	2000 (revised 2008)
Laws and regulations addressing residential appliances		
Directive on Eco-Design Requirements for Energy-Related Products [24]	Defines MEPS for energy-related products (refrigerators, freezers, dish washers, washing machines and televisions) and stand-by and off-mode losses of electronic equipment. Related to relevant EU Directive and Regulations.	2010
Directive on Displaying Standard Product Information and Labelling [25]	Requires energy labels for energy-related products (currently refrigerators, dish washers, washing machines and televisions) also aligned to EU law.	2011

The ***Energy Efficiency Law*** implemented in 2007 [15] covers principles and procedures applicable to increasing and promoting energy efficiency and renewable energies in all sectors and sets the framework for further implementation of more specific policies.

For the building sector, this law aims to create an institutional framework for supporting energy efficiency measures, including the establishment of an Energy Efficiency Coordination Board. Trainings, audits, consultancy, monitoring activities, and other support and/or incentives for energy efficiency projects are regulated by this law as well. The main entity assigned responsible for the implementation of the law is the General Directorate of Electrical Power Resources Survey and Development Administration (EIE). The provisions of the Energy Efficiency law which specifically addresses buildings include:

- Appointment of energy managers at commercial and public buildings over specified size and accreditation and support of ESCOs;
- implementation of minimum energy performance standards (MEPS) for buildings;
- establishment of ‘Building Energy Performance Certificates’; and
- application of individual heat meters for buildings with central heating systems.

Additional regulations and notifications have been published to implement the law, of which the most important are the Energy Efficiency Regulation and the Buildings Energy Performance Regulation. Both regulations were implemented in 2008 and revised a few years later.

The ***Energy Efficiency Regulation*** [16, 17] published in October 2008 describes mainly how ESCOs will be established, their training curricula set, and how they will be authorized. This regulation was fundamentally revised three years later after its first publication (October 2011). Although this regulation mainly focuses on the industrial, commercial and public buildings, it is also relevant for the residential sector as it requires labelling systems for energy-related appliances and equipment.

The ***Building Energy Performance (BEP)*** **Regulation** [18, 19] was implemented by the Ministry of Public Works and Settlement (MoPWS) in 2008 according to the requirements of the Energy Efficiency Law. It superseded the former Regulation on Heat Insulation in Buildings in 2009 and is designed in accordance with the European Union Energy Performance of Buildings Directive (EPBD). The BEP Regulation’s main objectives are:

- defining the calculation methods for the overall energy use of buildings;
- defining the performance criteria and their application principles and classifying the buildings with respect to the primary energy use and CO_2 emissions;
- determining the minimum energy performance (MEPs) requirements of existing buildings that undergo a major renovation;
- requiring new buildings to comply with efficiency class C;
- encouraging use of renewable energy sources (RES); and
- demanding from house owners to conduct periodic inspections of heating and cooling systems.

According to the BEP Regulation all buildings have to have a ‘Building Energy Performance Certificate’ by 2017, which includes information about the thermal efficiency, emissions, energy performance classification (A, B, C, D, E; F and G), insulation properties, heating and/or cooling systems of the buildings. Since January 2011 owning energy performance certificates has been mandatory for new buildings. The certificates are valid for 10 years [18, 19]. Until the end of February 2013 energy performance certificates have been given to 64,805 existing and new buildings [26]. In the light of this slow progress, the goal of 9 million certified buildings by 2017 seems relatively unrealistic.

Some other features of the BEP are:

- Central heating systems are mandatory for new buildings over 2000 m².
- Buildings with central heating systems have to use central or local heat/temperature control equipment as well as systems enabling the distribution of heating costs on the basis of heat utilization quantities.
- In buildings, single spaces or self-contained houses with gas fuelled space heating, or of a size of 250 m² and more the use of condensing gas boilers with integrated economizers is mandatory.

Compared to the EU countries with similar climate conditions the MEPS (i.e. heat transfer/U-Value) defined for new buildings is still lower in Turkey [47].

Another key legal act for building efficiency is the *National Standard of Thermal Insulation Requirements for Buildings TS 825*, which became mandatory in June 2000. Together with BEP, TS 825 provides the backbone for improving energy performance in buildings. It complies with international standards (ISO 9164 and EN 832) and:

- sets the thermal insulation requirement for new and existing buildings where renovation of at least 15% of the total area is carried out;
- defines the rules for the calculation methods of heating energy requirements in buildings

In addition to the mentioned regulations addressing buildings, the Turkish government also published regulations to encourage the use of energy-efficient home appliances.

These regulations mainly follow the standards and requirements set out in the EU Eco-Design Directives on Energy Using Products [27] and its successor on Energy-Related Products [28]. They are specified in the ***Regulation on Eco-Design Requirements for Energy-Related Products*** published by the Ministry of Science, Industry and Technology (MoSIT) in 2010 [24]. The regulation sets MEPS for refrigerators, freezers, dish washers, washing machines and televisions. It also regulates the stand-by and turned-off energy consumption of electronic home and office appliances. The MEPS require from retail sellers that all products of the above categories sold on the market in Turkey comply with the standards.

Furthermore, in December 2011 the Directive on displaying standard product information and labelling [25] was implemented, which requires energy labels for refrigerators, dishwashers, washing machines and televisions - aligned with EU labelling requirements.

The Strategic Energy Efficiency Plan (SEEP) 2010-2023

In 2004 an energy efficiency plan was drafted by the Government that has never been published. The Strategic Energy Efficiency Plan (SEEP) was not published until 2012 [34]. It provides a framework for the development of energy-efficiency policy until 2023 and targets for the improvement of energy efficiency combined with actions necessary to reach these targets. The main target is to reduce the amount of energy consumed per unit of GDP (energy intensity) by at least 20% until 2023 compared to 2011. The SEEP contains a total of seven strategic aims (SA) of which the following address the residential sector in particular.

- SA-2: Decrease energy demand and carbon emissions of buildings and promote sustainable environment-friendly buildings using renewable energy sources.
- SA-3: Achieve market transformation of energy efficient appliances.

SA-2 comprises two main targets.

First, it requires more ambitious efficiency standards for a particular category of existing buildings until 2023 (excluding small buildings, buildings in the scope of the urban transformation plan and rural buildings). To reach this target, the actions defined by the Government are:

- Revision of the current legislation on the energy performance of buildings (BEP) parallel to the EU regulations.
- Limiting the maximum energy demand and maximum CO_2 emissions of buildings.
- Defining the maximum energy demand of buildings according to their functions (hotels, dwellings, schools etc.), to the climate conditions of the region, to their architectural design and to the current mandatory standards considering heating, cooling and lightning.
- Determining the maximum CO_2 emissions for new buildings. Furthermore, in 2017 penalties will be applied to those buildings which exceed the defined CO_2 emission standards.
- Encouraging refurbishment of existing buildings to comply with CO_2 emission standards

Second, it requires that at least one fourth of the building stock from 2010 will be sustainable by 2023, while sustainability is not exactly defined.

SA-3 aims to complete the market transformation of lamps, refrigerators and electrical motors until the end of 2012 and for heating/cooling systems and other energy efficient products parallel to the EU regulations. To reach this target, MEPS are defined for each product group and controlled via market surveillance.

The General Directorate of Renewable Energy (YEGM) is responsible for realizing defined actions, applying the measures and evaluating the results for the next 11 years. The aims, targets and actions of the SEEP are going to be revised annually according to changes in governmental and EU policies.

Despite the positive intention of the government to improve energy efficiency, some questions regarding the application and time plan of the defined actions still remain open. According to the Chamber of Mechanical Engineers (TMMOB), many actions in the strategy plan are defined without analysing the present situation or without questioning the practicability in a short period such as 11 years in terms of capacity and budget. The time plan can be questioned even more for the building related measures, given the long lifetime of buildings. Taking these critics into account we extend our model-based analysis to the year 2035 to assess a possible long-term impact of the SEEP even after 2023.

Methodology

Structural framework and drivers

The applied bottom-up model for the Turkish residential sector – FORECAST-Residential – is based on a simulation approach. FORECAST-Residential includes a module for ‘household appliances, lighting and air conditioning’ (*Module 1*), and another module for ‘heating systems’ (*Module 2*). FORECAST-Residential is set up as a vintage stock model with detailed techno-economic parameters of energy end-uses in the residential sector (Figure 1). *Module 1* covers the appliance categories of white appliances, stoves, ICT appliances, lighting and air conditioning systems. The appliance categories listed contain exclusively electricity-based devices apart from stoves. The technological structure in *Module 1* considers three hierarchical levels of household appliances (e.g. televisions) on the highest level of aggregation, which are further differentiated by technology (e.g. plasma, LCD) and then divided again into efficiency classes (e.g. A++, A+). The *Module 2* for heating systems is based on the existing useful energy demand, which is derived from the Turkish building typology. The building typology is subdivided by construction period, building type and multiple refurbishment levels. The heating systems are discretely assigned to the different building segments.

Modelling of technology diffusion

Decision-making in private households is based on the observation that each decision maker selects the option which offers the highest individual benefits or utility from a large number of alternatives [8]. This concept is based on the studies of Thurstone, who examined the influence of psychological stimuli on individual’s decision behaviour [9]. Ultimately, this concept was further developed by Marschak, who interpreted the stimuli as individual benefits and then derived the phenomenon of maximizing utility from this [41]. Due to the fact that the decision makers in private households differ with regard to their preferences, lifestyles, available information and other characteristics, individual utility is a complex variable and to a certain extent not quantifiable [42]. However, because satisfying a utility always results from the decision in favour of one alternative, at the macroeconomic level, the sum of all decisions can be described if this is linked to measurable variables. Logit models are used to illustrate this type of decision logic in energy models [7]. The market share of substitution alternatives can be determined from a market perspective using a Logit model by means of observable variables (e.g. investments). Three properties have to be given for a Logit model to be applied [42].

- The substitution alternatives have to mutually exclude one another from the decision maker’s perspective.
- All the substitution alternatives have to be included in the decision-making.
- The number of substitution alternatives has to be finite.

In line with the heterogeneous utility function of the decision maker, the Logit approach delivers a distribution of market shares as the result, which takes all the substitution alternatives into account. The main descriptive factor which influences the utility function is the Total Cost of Ownership (TCO): the investment sum plus payments for energy and maintenance [13, 14]. By determining the correlation between TCO and the market shares of competing technologies the price elasticity is

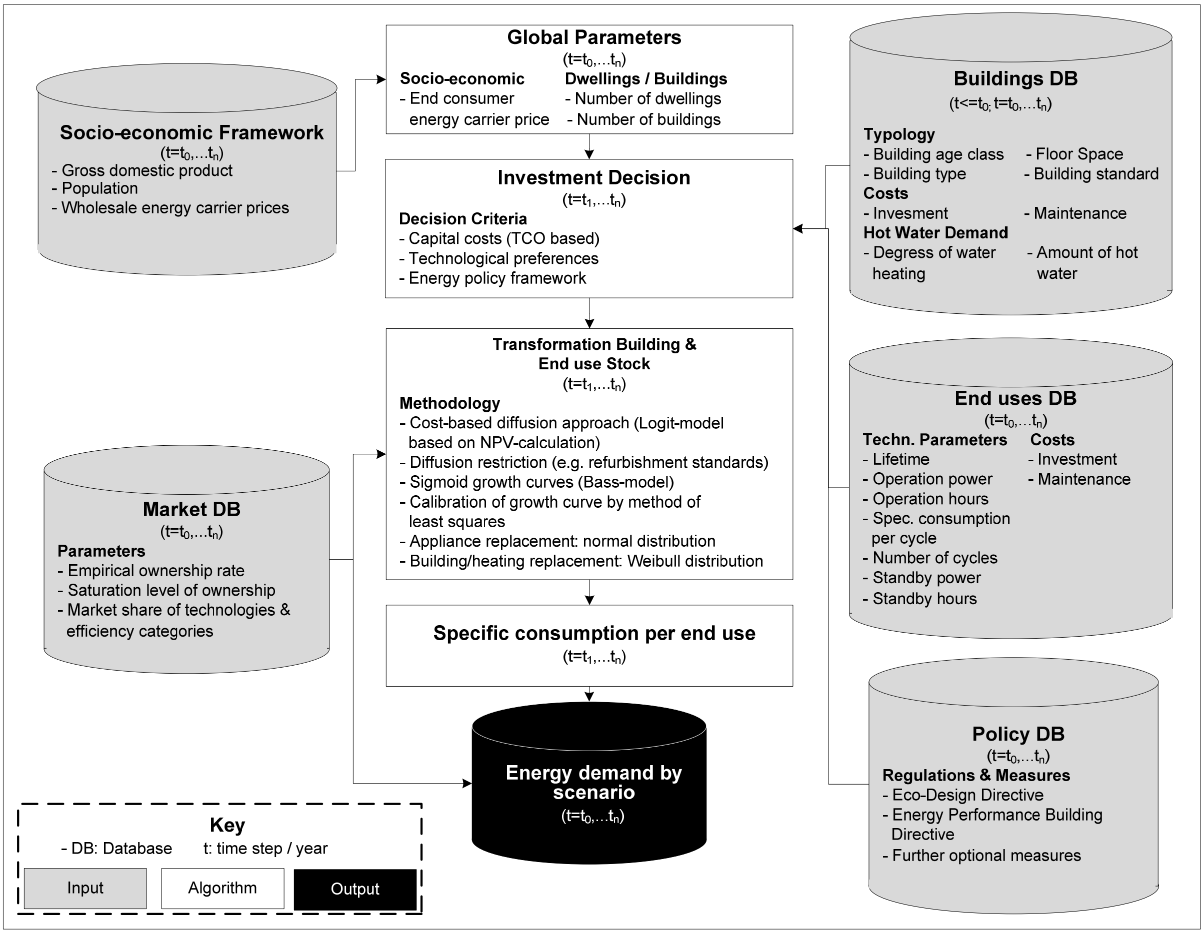

Figure 1: Structural framework of FORECAST-Residential

explicitly taken into account using the Logit approach [7]. As in a real investment decision only limited knowledge is available about the period of the investment cycle the investment decision is based on a calculation with myopic information [10]. Calculating the TCO is done using a dynamic net present value calculation and subsequently an annuity calculation, which makes it possible to compare different investment alternatives in monetary terms.

The Logit approach aims at quantifying the market shares of rival alternatives (e.g. replacement of heating systems). Furthermore, growth curves are used to determine the total number of investment decisions in each year, if there is no substitution relationship between end-uses. This is the case for all end-uses captured by *Module 1*. Another function of the growth curves is to consider market dynamic and saturation effects. Growth curves are based on an epidemic interpretation of market growth, which uses the empirical market growth as the basis for projecting the growth curve [8]. These generally S-shaped curves can be described by different explanatory approaches of technology diffusion. Since a large number of analyses has already revealed that word-of-mouth represents the main driver of technology diffusion, an extended version of the Bass function was chosen, which also takes income elasticity into account [11, 12, 46]. The saturation point of equipment penetration rates was derived, among other things, from the disposable income [12, 45]. The Bass function is fitted by a least squares deviation based on empirical stock development and the saturation point. The stock turnover of appliances is calculated by a normal distributed failure probability, which is used to determine the point in time at which the lifetime of an old appliance ends [7]. The probability of building demolition and heating replacement is calculated based on the age distribution using a Weibull distribution [44].

The final energy demand of appliances is calculated according to the average penetration rate (for lighting, this corresponds to the share of lighting points per dwelling), the market share of the technologies and efficiency classes, the specific consumption (based either on the number of operating hours, for example, of televisions, or on the number of cycles per year, for example, of dishwashers), and the number of dwellings. The final energy demand of heating systems is calculated in two steps: in a first step the useful energy demand is quantified based on the building typology and in a second step it is transformed into the final energy demand by the heating systems.

Scenario analysis

Scenario definition

To analyse the impact of alternative policy strategies on the residential energy demand in Turkey an ex ante scenario analysis is applied. For all scenarios similar assumptions are taken for the socio-economic parameters such as population, GDP or number of dwellings. As only the techno-economic parameters depend on the scenario specific policy framework, the difference in energy demand between the scenarios equals the impact of the analysed policy packages. The three explorative scenarios are distinguished as follows:

- *Reference scenario (REF-S)*: technological changes are driven by autonomous progress and policies implemented until 2012 are considered (see Table 1). The SEEP is explicitly excluded.
- *Strategic Energy Efficiency Plan scenario (SEEP-S)*: according to the SEEP more ambitious efficiency standards and new regulations regarding energy efficiency are included.
- *High efficiency scenario (HiEff-S)*: based on the SEEP scenario, but assumes more ambitious policies in fields where the SEEP still remains at a lower level of ambition. This scenario shows what is possible beyond the current Turkish strategy.

The policy-related assumptions are discussed in the following and summarized in Table 2 and Table 3.

Buildings

Thermal efficiency of buildings (kWh/m²a): According to the BEP regulation, the efficiency of new buildings must correspond at least to energy class C. The thermal efficiency of a class depends on the climatic zones, the architectural design and the building type. We used the reference parameters for different climatic zones defined in the BEP to calculate average thermal efficiencies of building envelopes for energy class C for single-family houses (SFH) and multi-family houses (MFH). To receive an average value for the thermal efficiency per building segment, the thermal efficiency per climate zone is weighted by the number of residents living in this zone. The resulting MEPS for single-family and multi-family houses are approximately 269 kWh/m²a and 254 kWh/m²a, respectively. For existing buildings, the REF-S contains no restrictions. In the SEEP-S existing buildings have to comply with efficiency class C, if they are multi-family houses with a floor area above 10.000 m². The HiEff-S is more ambitious and applies thermal efficiency standards for both types of existing buildings.

Refurbishment rate (%): The refurbishment rate only describes the energetic refurbishment of buildings. Empirical data on the refurbishment rate in Turkey is scarce. The REF-S assumes a business as usual refurbishment rate of 0.9%, based on analogous assumptions from other European countries [29]. In the SEEP-S the refurbishment rate starts at 0.9% and then approaches its maximum of 2.08% in 2023 and remains at this level. The increase is derived from the SEEP goal to make at least a quarter of the 2010 building stock sustainable until 2023. In the HiEff scenario the refurbishment rate increases earlier to 2.08% and then remains at this level.

Demolition rate (%): The demolition rate gives the share of the building stock demolished each year. The Urban Transformation Plan [30] requires that a number of 6.5 million buildings are demolished until 2030. The resulting demolition rate equals 1.71% and is assumed constant for all scenarios. The related construction rate is calculated endogenously based on the exogenously given number of dwellings per year or building stock, respectively.

Other parameters like the *interest rate* [32], *investment subsidies* [33] and the *compliance rate* [29], which are not mentioned in the policy measures of Turkey, are quantified related to other studies for each scenario.

Table 2: Relation of model parameters and scenarios – buildings

Category	Parameter	Unit	REF-S	SEEP-S	HiEff-S
Buildings	**Control and Regulatory mechanisms**				
	Thermal efficiency (existing buildings)	kWh/m²a	No restrictions	Minimum efficiency class C (MFH: 254 kWh/m²a)	Minimum efficiency class A (SFH: 107 kWh/m²a, MFH: 101 kWh/m²a)
	Thermal efficiency (new buildings)	kWh/m²a	Minimum efficiency class C (SFH: 269 kWh/m²a, MFH: 254 kWh/m²a)	Minimum efficiency class A (SFH: 107 kWh/m²a, MFH:101 kWh/m²a)	Minimum efficiency of 30–80 kWh/m²a for SFH and MFH
	Refurbishment rate	%	Constant at 0.9%	0.9 % until 2012, increase to 2.08 % until 2023 and remains constant	0.9 % until 2012, instantaneous increase to 2.08 % in 2013 and remains constant
	Compliance rate	%	Increases from 60 to 70 % until 2030	Increases from 60 to 85 % until 2030	Increases from 60 to 90 % until 2030
	Demolition rate	%	Constant over time (1.71 %)		
	Financial instruments and incentives				
	Interest Rate	%	7%	7%	3%
	Investment Subsidies	%	No subsidies provided	No subsidies provided	15% of investment

Heating systems

Diffusion restrictions for heating technologies: According to the BEP regulation, existing buildings with a floor area of 250 m² and more must use a condensing boiler with integrated economizer [19]. We calculate the affected building stock based on the floor area distribution as given in the building census from 2000 [31] resulting in a share of 4.78% for the existing buildings. For new buildings of 2000 m² and more the BEP regulation requires central heating systems. We assume that 2000 m² correspond to multi-family houses with 8 or more dwellings. In 2010 this building class made up 62.5% of all multi-family houses that received a construction permit in that year [35]. We assume the share to remain constant over time. Both requirements are assumed to be similar for all scenarios.

Other parameters like *interest rate* and *investment subsidies*, which are not part of the current policy mix in Turkey, are assumed for the HiEff-S to arrive at a similar level as in Germany. Accordingly, the HiEff-S foresees a lower interest rate and an investment subsidy of about 16.4 percent for heat pump systems [32].

Appliances

MEPS: In the REF-S MEPS are defined for seven residential appliances (refrigerators, freezers, dish washers, washing machines, dryers, air-conditioners and televisions). In the SEEP-S MEPS are additionally set for lamps and the standards for the other products are updated according to EU Eco-Design law. For the HiEff-S we assume that MEPS are not set according to least lifecycle cost, but instead based on the best available technology (BAT).

Other parameters like *interest rate* and *investment subsidies*, which are not part of the current policy mix in Turkey, are assumed for the HiEff to arrive at a similar level as in Germany.

Table 3: Relation of model parameters and scenarios – heating systems and appliances

Category	Parameter	Unit	REF-S	SEEP-S	HiEff-S
Heating systems	**Control and Regulatory mechanisms**				
	Diffusion restriction (Existing Buildings)	%	4.78% of existing building stock must use condensing type of heaters		
	Diffusion restriction (New buildings)	%	62.5% of new buildings after 2009 must have central heating system		
	Financial instruments and incentives				
	Interest Rate	%	7%	7%	3%
	Investment Subsidies	%	No subsidies provided	No subsidies provided	16.4 % of investment for heat pump systems in existing and new buildings
Appliances	**Control and Regulatory mechanisms**				
	MEPS	%	MEPS for refrigerators, freezers, dish washers, washing machines, dryers, air-conditioners and televisions	Additional MEPS for lamps and more ambitious MEPS for other appliances	Standards more ambitious than SEEP scenario based on BAT
	Financial Instruments and Incentives				
	Interest Rate	%	7%	7%	7%
	Investment Subsidies	%	No subsidies provided	No subsidies provided	20% of investment for high-efficient appliances combined with duty to return the old appliances

Socio-economic and techno-economic parameters

The socio-economic parameters including the population, number of households, gross domestic product (GDP), and energy carrier prices are similar across the three scenarios (see Table 4) [1, 3, 36, 52, own calculation]. Turkey's population will continue to rise in the future and is estimated to reach 86.7 million in 2030. The demand for new houses will also increase, resulting from the rising population. Energy carrier prices for households are expected to increase as well.

Table 4: Summary of socio-economic model parameters and energy carrier prices in the period 2008-2030

	Unit	2008	2010	2015	2020	2025	2030
Socio-economic parameters							
Population	Million	70.9	72.8	77.0	80.8	83.9	86.7
Pers. per household	Pers./HH	4.01	3.95	3.79	3.66	3.53	3.42
Number of households	Million	17.7	18.4	20.3	22.1	23.8	25.3
GDP	Billion Euro ‘05	798	726	857	987	1117	1247
Energy carrier prices							
Electricity	Cent / kWh ‘10	12.2	12.7	12.7	14.3	15.6	16.3
Light fuel oil	Cent / kWh ‘10	13.3	12.3	12.0	12.5	13.6	13.9
Coal / lignite	Cent / kWh ‘10	3.66	4.19	4.56	4.47	4.61	4.70
Natural gas	Cent / kWh ‘10	4.67	4.38	4.81	4.74	5.00	5.24
Biomass	Cent / kWh ‘10	3.63	4.69	5.42	5.25	5.53	5.70
District heating	Cent / kWh ‘10	7.62	7.63	9.80	9.50	10.7	11.8

Assumptions on technological parameters (e.g. operation hours and operation power, lifetime) are based on various market and technology studies, particularly for large appliances, ICT-appliances, air-conditioning as well as lighting [37, 38, 39, 40]. The stock of residential appliances in 2008 is represented by multiplying the ownership rate with the amount of households. The ownership rate and the specific energy consumption (SEC) of appliances in 2008 are listed in Table 5.

Regarding the prospective development of technological parameters until 2030, the ownership rate is developing identically in all scenarios, whereas the SEC of appliances depends on the scenario. For many appliances (except for freezers, wash machines, dishwashers and dryers) the ownership rate has almost reached the level of saturation. The ownership rate of ICT appliances will increase significantly during the next decades. For ICT appliances the saturation level of ownership is derived from the amount of people living in a household whereas for large appliances the saturation rate is linked to the overall household. Due to an increasing demand of individual comfort the market share of air conditioners will continue to grow in the future.

Table 5: Ownership rate and specific energy consumption (SEC) of appliances in 2008

Appliance group	Appliance	Ownership rate [number/household]	SEC [kWh/year]
Large appliances	Refrigerator [37]	1.01	233
	Freezer [37]	0.06	373
	Dryer [37]	0.05	271
	Dishwasher [37]	0.36	194
	Washing machine [37]	0.87	174
ICT appliances	Desktop Computer [1]	0.27	154
	PC screen [1]	0.27	90
	Laptop [1]	0.11	73
	Television [39, 48, 49]	1.04	243
	Set-Top Box [39, 48, 49]	0.35	76
	Modem/Router [1]	0.23	88
Lighting	Lighting [51]	1.00	438
Air-Conditioner	Air Conditioner [40, 50]	0.11	633

Results

The results for the future development of energy demand are shown in Figure 2. All scenarios show a decreasing demand starting from the level of 944 PJ in 2008. In the REF-S final energy demand decreases to about 851 PJ by 2030, while the SEEP-S adds additional savings of about 13% and arrives at about 736 PJ in 2030. The more ambitious HiEff-S results in 659 PJ in 2030 equal additional savings of about 10%.

In the SEEP scenario, the share of electricity and solar thermal energy increases continuously until 2030. Electricity demand increases from 143 PJ to 190 PJ (33 %) by 2030 and solar thermal energy reaches about 0.3 PJ in 2030, starting from nearly zero. On the other hand, conventional fuels decrease over time. The demand for oil diminishes from 63 PJ to 22 PJ (-65 %), coal and lignite decrease from 248 PJ to 152 PJ (-39 %) and natural gas from 272 PJ to 224 (-18 %). Also the energy demand for (mostly traditional) biomass decreases constantly (-38%), losing its position as the third most important energy carrier. It is substituted by electricity, district heating, and solar thermal heating. Thus, conventional fuels lose their share and decrease in absolute numbers, while the share of renewable energy sources (RES) and electricity increases. In the HiEff-S, the trends by energy carrier are similar, but even more pronounced.

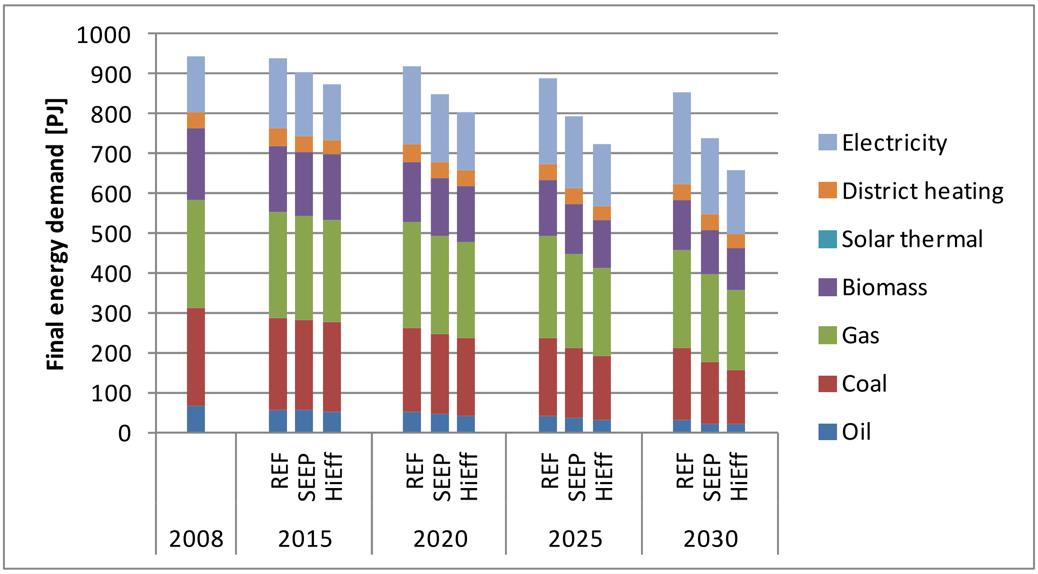

Figure 2: Final energy demand by energy carrier and by scenario for the period 2008-2030

As discussed above, demand for energy sources mainly used for space heating decreases in all scenarios. This development marks a structural break with the increasing demand in the past and is mainly due to a falling useful energy demand for space heating in buildings. Two main factors can be identified that drive space heating demand down: the (very ambitious) urban transformation plan resulting in very high demolition rates and a quick stock turnover as well as the low efficiency level of the existing building stock. In combination with the assumption of a relatively high compliance rate, space heating demand decreases significantly – even in the REF-S (see Figure 3).

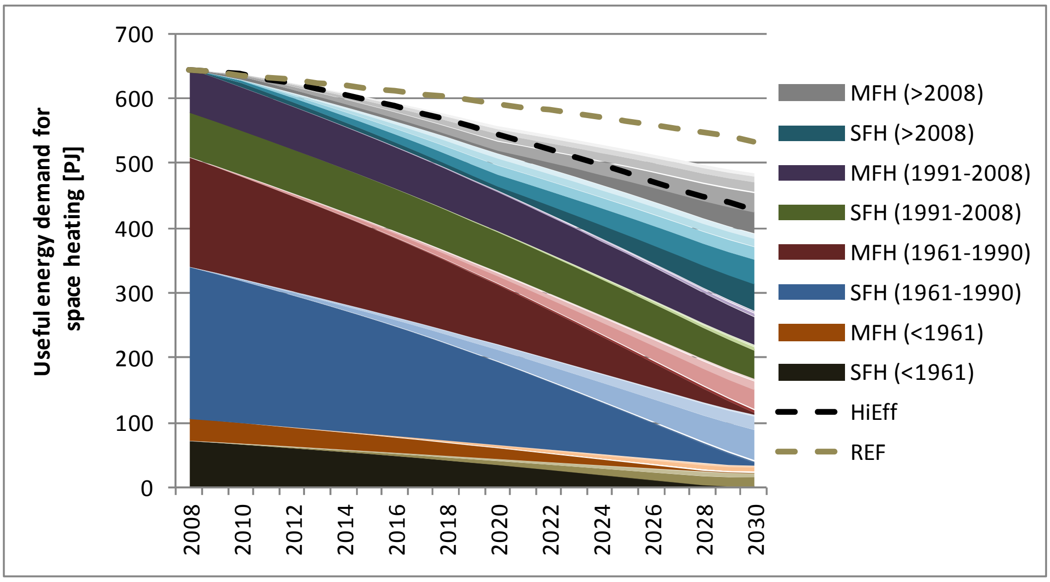

Figure 3: Useful energy demand for space heating by construction period and building type for the period 2008-2030

The SEEP-S assumes more ambitious MEPS for buildings and a high refurbishment rate resulting in additional useful energy savings of about 10% until 2030. The development of space heating demand by building type in Figure 3 reflects the high refurbishment rate and stock turnover, as the existing building categories are mostly refurbished or replaced by 2030. As a result, new buildings account for about one half of the space heating demand in 2030. While the SEEP-S is already relatively ambitious, the HiEff-S achieves an even faster efficiency improvements induced by a higher refurbishment rate and more ambitious standards.

Figure 4 shows the results for heating energy demand until 2030, which in total follows the shape of the useful energy demand for space heating. In the SEEP-S, the distribution among energy carriers changes only slowly. Natural gas and district heating increase continuously, at the cost of coal, oil and biomass. Also the use of heat pumps and solar thermal energy grows substantially, but remains on a very low level. Generally, the substitution among energy carriers is relatively low because no policy measure particularly addresses individual heating systems. This is different in the HiEff-S where a subsidy is provided for the installation of heat pump systems. But even in this case, only marginal changes are induced and the sensitivity analysis reveals that subsidies for heat pumps must be substantially higher to have any effect on heating system shares.

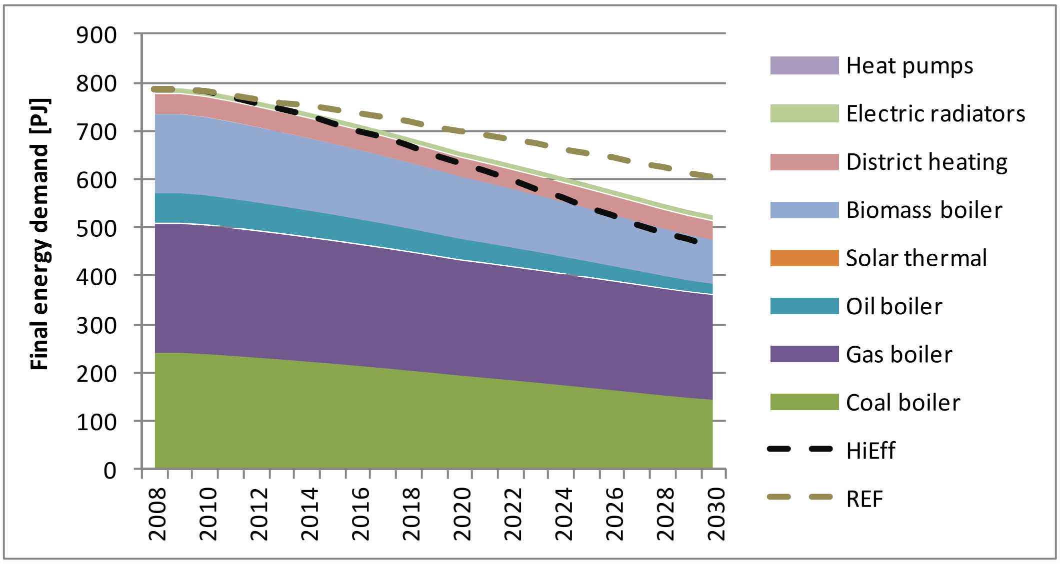

Figure 4: Final energy demand of heating systems by system type and by scenario for the period 2008-2030

Figure 5 shows the electricity consumption of large appliances, lighting and other appliances under different scenarios. In the REF-S, the electricity consumption of large appliances increases from 10 TWh in 2008 to 12 TWh in 2030. Also in the SEEP-S, electricity demand increases continuously, but is 15% lower in 2030 than in the REF-S, mainly due to more ambitious MEPS. The HiEff-S reveals further saving potentials of about 19% by 2030 compared to the SEEP-S resulting from more ambitious MEPS set at BAT level.

Electricity consumption of lighting increases in the REF-S from 8 TWh to 9 TWh in 2030, whereas in the SEEP-S it decreases to 4 TWh in 2030, resulting in savings of 54% compared to REF-S. These high savings mainly result from the fact that the REF-S does not contain MEPS for lighting, which are introduced in the SEEP scenario in line with EU legislation. In the HiEff-S, consumption decreases even more to 2 TWh (-75% compared to REF-S), reflecting MEPS based on BAT which results in a fast diffusion of LED technology.

A third groups comprises the remaining appliances including IT, air-conditioning but also a high number of small appliances not individually modelled as well as potential new appliances arising in the future. These groups of appliances generally show a growing trend, which also is reflected in the scenarios, as even in the HiEff-S demand increases substantially until 2030. The policies defined in the SEEP only induce a small mitigation of about 8% compared to REF-S, resulting in a growth of 68% compared to 2008. This increase indicates the importance to regulate this heterogeneous group of appliances as well as the difficulty to do so.

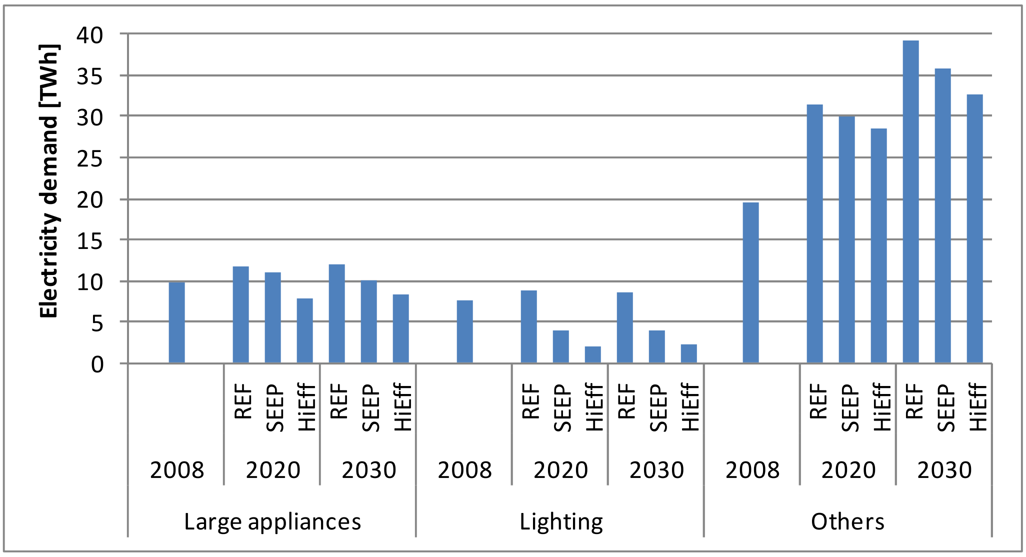

Figure 5: Electricity demand of large appliances, lighting and others electricity user by scenario for the period 2008-2030

Figure 6 shows the share of individual efficiency classes and its evolution in the stock of dryers for the SEEP-S. It shows that MEPS introduced in the SEEP result in a complete phase-out of class E and D appliances by 2020 and class C appliances by 2025. On the other hand, in the long term even new efficiency classes (A+++ and beyond) emerge and gain substantial shares in the stock of dryers.

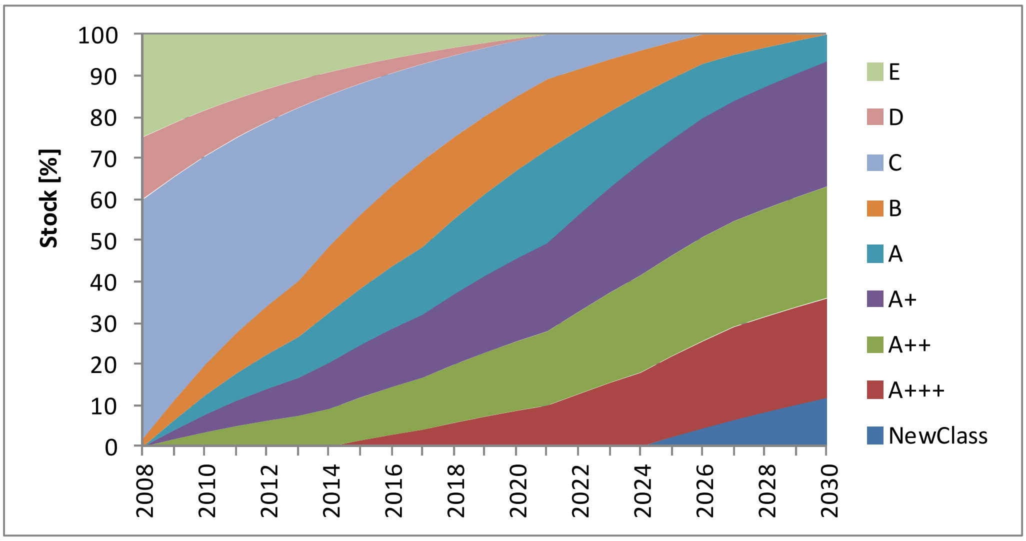

Figure 6: Share of efficiency classes in the stock of dryers for the SEEP-S and its evolution

Conclusion and Outlook

We applied an explorative scenario analysis to assess the ex-ante impact of the current and future energy-efficiency policies in Turkey on the final energy demand of the residential sector until 2030. The three scenarios use the same socio-economic framework data, but differ regarding techno-economic data depending on the policy design. The reference scenario (REF-S) represents the basis for impact calculation and considers the current policy-mix. The second scenario SEEP-S is based on the policy measures of the strategic energy efficiency plan (SEEP), which was published in 2012 by the Turkish Government and provides the framework for an energy-efficiency strategy until 2023. The third scenario (HiEff-S) assumes even more ambitious efficiency standards (such as BAT assumption for MEPS) and aims to identify potentials for efficiency improvement beyond the SEEP.

The results show that the final energy demand decreases in all scenarios from about 944 PJ in 2008 to 851 PJ (REF-S), 736 PJ (SEEP-S) and 659 PJ (HiEff-S) in 2030. The decreasing demand even in the REF-S reflects a structural break with the past and is mainly coming from the building sector driven by a very high demolition rate (due to the urban transformation plan) and a very low level of efficiency in the existing building stock. In the SEEP-S, most existing buildings will be either refurbished or demolished by 2030 indicating the high level of ambition behind these assumptions.

Electricity not only gains in its share but also increases in terms of total demand in all scenarios - driven by ownership growth of various electric appliances. The SEEP-S achieves 10 TWh of savings in 2030 compared to the REF-S, mainly originating in more ambitious appliance and lighting standards.

Thus, regarding the policy mix we can conclude that the SEEP achieves considerable energy savings, but also significant saving potentials still remain. 6.5 million buildings will be demolished until 2030 through the Urban Transformation Plan, and new buildings have to comply with thermal efficiency standards. This window of opportunity is, however, not addressed by the current building efficiency standards that on average require a minimum thermal efficiency of around 254 kWh/m²*a for single family houses. The SEEP is not very specific with regard to the thermal efficiency required, besides demanding higher standards from future building regulations. A central conclusion from our analysis is to apply more ambitious standards for buildings in this framework and make use of the current window of opportunity. The results of the SEEP scenario, however, have to be interpreted with caution, as the SEEP is still rather vague in many aspects (e.g. sustainability of buildings is not exactly defined) and open to interpretation in order to translate it into model parameters.

The analysis also contains elements of uncertainty. The outline of the scenarios follows very closely the policy requirements as described in the various legislative documents including a high rate of building demolition and refurbishment and an assumed compliance rate on a similar level as observed in EU countries. Thus, the scenarios assume a strong enforcement which might not be the case in the coming years. Still, the comparison of the scenarios shows the order of magnitude of the SEEP's impact and the fields where it has the strongest effect (building standards, refurbishment rate, lighting standards).

From the methodological point of view, it is worth mentioning that our analysis is the most detailed bottom-up assessment of the Turkish residential sector – at least to the knowledge of the authors. Most other studies rely on top-down approaches, which have the disadvantage that they are not able to model policies that address particular technology parameters like the thermal efficiency of buildings. One disadvantage, however, of the bottom-up approach is the high need for very detailed data. While we were generally able to fill all required model input parameters with sufficiently reliable data, room for improvement certainly remains. Sometimes even data sources differ from one another as it is the case with the number of households.

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Nigerian Energy Efficiency Standards and Labels Initiative: Progress So Far and Lessons Learnt

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United Nations Development Programme

Abstract

With support from the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) in collaboration with relevant government agencies has commenced the implementation of a project in Nigeria. The overall objective of the Project is to improve the energy efficiency of selected end-use appliances used in residential and public sector in Nigeria through the introduction of appropriate energy efficiency policies such as standards and labels (S&L) and demand-side management programs. Such interventions will help to reduce Nigeria's energy-related CO_2 emissions by reducing the demand for energy (electricity). An understanding of the national level of efficiency of targeted appliances is imperative to establish the baseline for Minimum Energy Performance Standard (MEPS) in any country. This initiated the end-use monitoring study across the six geopolitical zones of Nigeria to assess the current level of energy efficiency of selected appliances (lighting, refrigerators and air conditioners). A total of 200 households were monitored during the study. The household volunteers were selected at random and based on income status. Data logger devices such as serial wattmeter, wattmeter with ammeter pliers, lamp meters and temperature sensors were used to collect energy related data over a period of one month (30 days) from each household. This paper will present the preliminary report of the study in Abuja while comparing data with other countries where similar studies were done. The paper will also enumerate the challenges and lessons learnt in the process of introducing standards and label to transform the appliance market in Nigerian.

Introduction

With a population of well over 160 million people, only about 40% of Nigerians have access to electricity. In places where there is access to electricity (mainly in the urban areas), consumers of electricity suffer from frequent power outages that last for several hours. The survey conducted in three large cities in Nigeria – Abuja, Lagos and Benin City revealed that over 80% of those interviewed do not get electricity supply for up to 24 hours a day (CREDC, 2009).

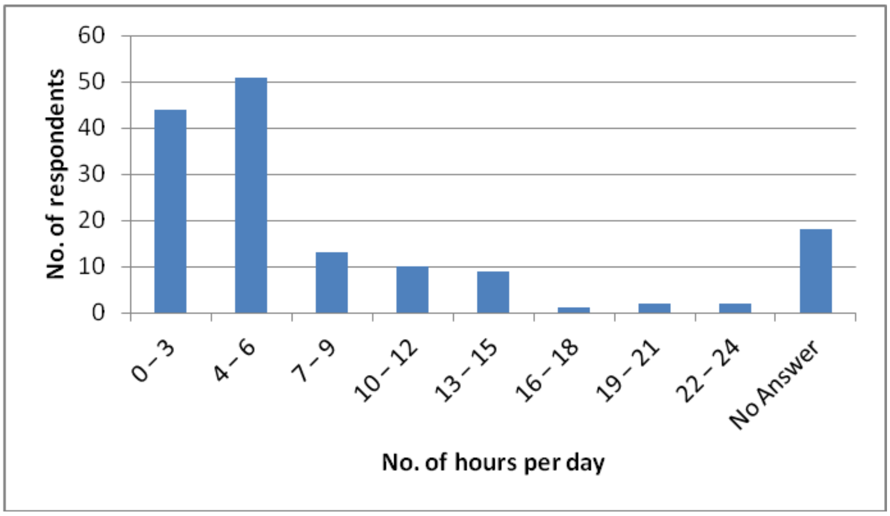

Fig. 1: The numbers of hour respondents get electricity per day

It was reported in 2012 that Nigeria reached grid generating capacity of about 4,477.7 MW of electricity (Daily Times, August 15th, 2012); this capacity however fluctuates for reasons such as shortage of gas supply, lack of maintenance, technical hitches etc. Apparently, this is grossly inadequate for the Nigerian population, which is about 25% of the population of sub-Sahara Africa. The unstable and inadequate power supply have forced a large portion of the industry, businesses and households to rely on diesel and petrol generators as primary or back-up source of electricity. This is expensive and a source of noise and air pollutions. More also, a large part of the energy generated is wasted due to the wasteful behaviour and the use of energy intensive technologies.

Energy consumption contributes to about 25% to 30% of energy-related CO_2 emission, accounting for 26% of all anthropogenic CO_2 emission and 14% of global net contribution to climate change from greenhouse gases (Wiel, 1998). Energy efficiency programmes/projects are ways that have been identified to reduce the impacts of energy generation on the fragile environment and at the same time increase access to electricity. Moreover, energy efficiency will play a pivotal role in the mitigation of climate change as asserted in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). Energy efficiency measures have the potential to promote economic development and can lead to job creation and create opportunities for savings of personal income. The efficient use of energy will help to reduce family energy bill. It will avoid the need to build more power stations, thus the money saved could be spent on other sectors of the economy and the energy saved will make it possible for more people will have access to energy.

It is against this background that the United Nations Development Programme (UNDP) with support from the Global Environment Facility (GEF) and in Collaboration with the Federal Ministry of Environment (FME), the Energy Commission of Nigeria (ECN), and the National Centre for Energy Efficiency and Conservation (NCEEC) commenced the implementation of a project to promote energy efficiency best practices in Nigeria. The overall objective of the Project is to improve the energy efficiency of selected end-use appliances used in residential and public sector in Nigeria (refrigeration appliances, air conditioners, lighting, electric motors, etc.) through the introduction of appropriate energy efficiency policies and measures, such as standards and labels (S&L) and demand-side management programs. The project is to reduce Nigeria's energy-related CO_2 emissions by reducing the demand for energy (electricity) in the country's residential and public sectors through the introduction of energy labels and minimum energy performance standards (MEPS) for new equipment and appliances (UNDP GEF, 2011).

The on-going UNDP GEF project will assist the Nigerian government to set MEPS for selected appliances. MEPS are useless if there are no mechanism and facilities to enforce them. Consequently, the Project will assist the Nigerian government in the area of enforcement of energy efficiency policies and laws by helping to set up testing centres in Nigeria to test the energy efficiency of appliances. The project is also designed to create awareness to change behaviour and build the capacity of relevant stakeholders in the country to promote energy efficiency. The objective of this paper is to share the progress made so far as well as share the success stories and lesson learnt. The paper will give the preliminary report of the end-use energy monitoring study which was conducted in the six geopolitical zones of Nigeria. The study is on-going, thus the paper will present the report of the study that was conducted in the Federal Capital Territory, Abuja to represent the North-Central Geopolitical Zone of Nigeria. The data collected will be compared with data collected in other part of the world where similar study has been carried out.

Methodology for the Study

The locations for metering study were assigned to six geopolitical zones of Nigeria– from Abuja (North Central), Sokoto (North West), Bauchi (North East), Benin City (South South), Nsukka (South East) and Lagos (South West)- (see figure 2 below). As part of the study, a total of 200 households were monitored and surveyed, an average of 35 households from each of the six geopolitical zones of Nigeria. Another 20 households will be monitored continuously for 12 months to study seasonality impact. The criteria for choosing households included the size of the family and the socio-economic status such as the income level. A total of 35 households were monitored during the study in Abuja. The data logger devices were used to collect data for a period of one month (30 days) from each household. The baseline data of each household were recorded that included name, address, annual income, family size, age and type of appliances, size (volume capacity), energy rating on the nameplate (where exist) and brand/made.

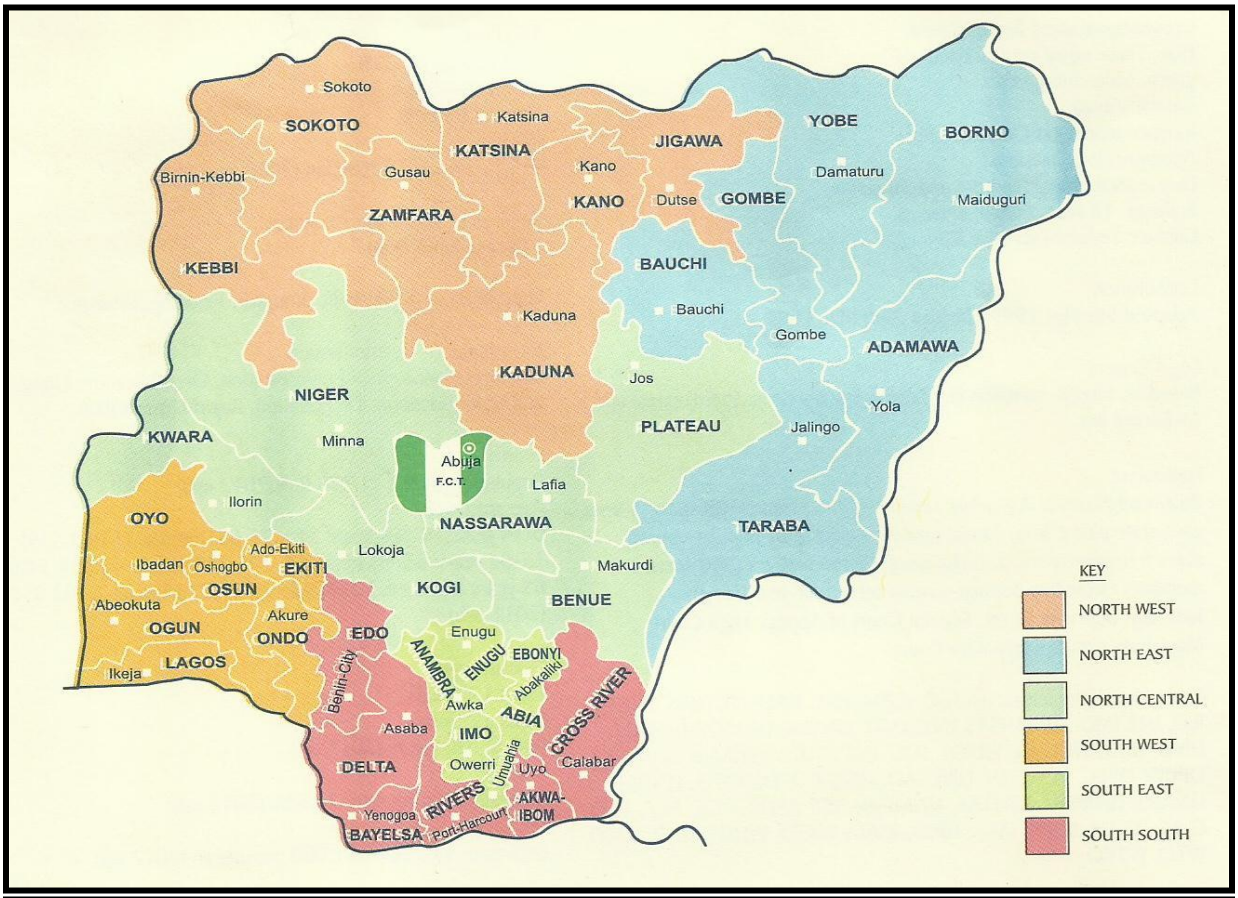

Figure 2: Map of Nigeria showing the six geopolical zones

The study team collected data using different electronic data logger devices. Data logger devices are portable devices used to directly measure electric consumption of different appliances. Three different data loggers were used for monitoring during the study. They included a *serial wattmeter,* which was designed to measure the active energy and voltage for single-phase appliances with power level lower than 2.6 kW. The device was placed in serial between the standard socket-outlet (designed to accommodate voltage from 0-250 V) and the plug of the appliance to be measured. The *serial wattmeter* can be left in place several months according to the frequency of the selected data memory - memory can record data for up to 13 months. At the end of the measurement period, the data recorded were uploaded to a computer for analysis using the Oscar software. The Serial Wattmeter was used to collect data from refrigerators and lighting equipment that are plugged to wall sockets.

The other equipment used was the Multivoies (multichannel) meter device, that is designed for the measurement of a large number of channels of power consumption and energies from electrical switch boxes. It includes a Din rail mounted concentrator to measure voltages and supplied power to the system, and several modules equipped with current sensors. The memory of the Multivoies can collect data for up to 4 months. If recording is required for more than 4 months, the device can be reset to collect more data. The Multivoies system can interface with Personal Data Assistant (PDA) using infrared communication or low power radio (Bluetooth). The Multivoies meter helped to collect the total consumption from the household, energy consumption from air conditioners and lighting equipment that are not connected to wall socket.

The third equipment was the electronic thermometers, that were installed in all the houses monitored to provide information on the temperature changes during the time of measurement. The thermometer is an autonomous electronic data logger of reduced size provided with temperature sensor. It takes regularly measurements and stores at selected time steps the average of several measurements (2 minutes interval between each measurement). The thermometer has a very broad range of measurements (-50°C to 120°C). The data are stored in a non volatile memory of strong capacity (64Ko) allowing a recording going up to 65,000 measurements (1 byte per data, for an autonomy of approximately 1 year and 3 months for recordings with the step of 10 minutes).

Result of Study

Only preliminary results are presented here to illustrate the types of data that could be collected and presented. Out of the 35 households monitored during the study in Abuja, 18 of them had air conditioners installed in them. From Fig. 3 below, the highest energy consuming air conditioner was recorded as 3,307 kwh/annum while the lowest was approximately 92 Kwh/annum to give an average of 1387 kWh/annum.

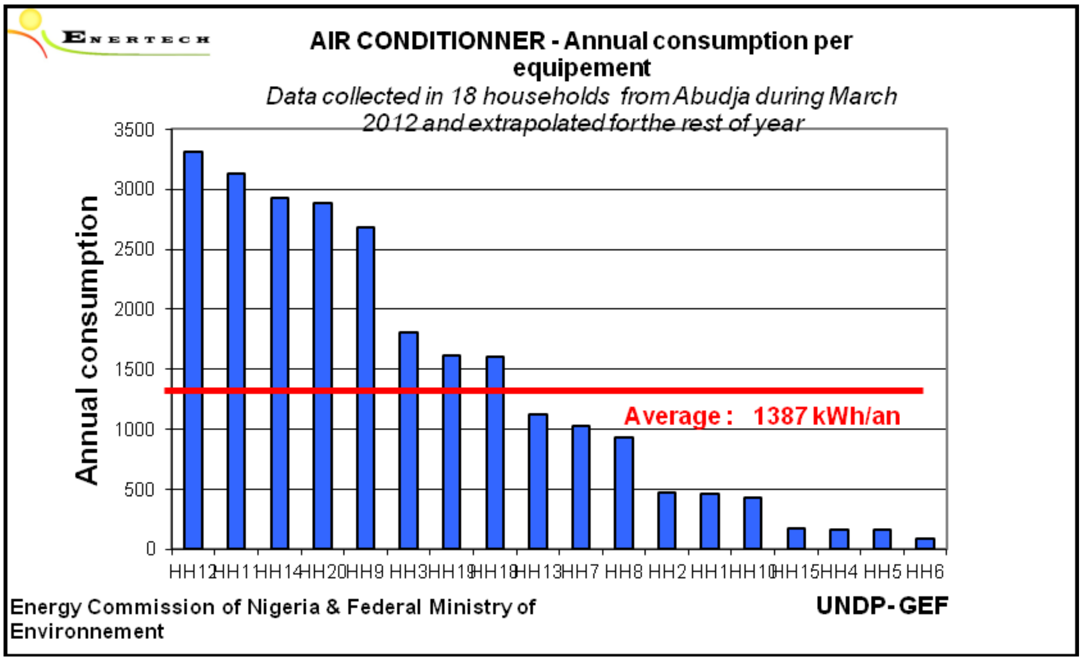

Fig 3: Annual consumption of air conditioners monitored in Abuja

Many of the houses monitored had one or more of the following appliances – fridge-Freezer (having both a fridge and freezer compartment), Fridge (only fridge compartment) and freezer (having only freezer compartment). A total of 13 households had fridge-freezer cooling systems. The average annual consumption for fridge-freezer was recorded as 698 kWh/annum; the highest consumption was recorded as 1230 kWh/annum while the lowest was 427 kWh/annum.

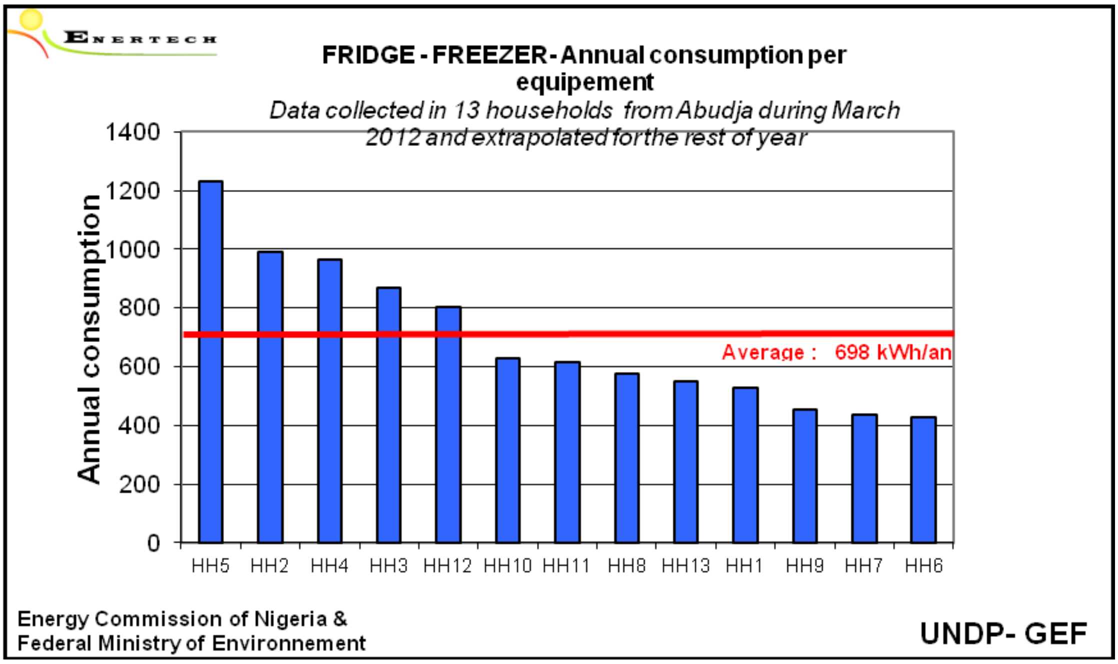

Fig. 4: Annual consumption of fridge-freezer monitored in Abuja

Freezers (popularly called deep freezers) were found in 16 households out of the 35 households monitored. The average annual consumption for freezers was 756 kWh/annum, the highest consumption was approximately 1318 kWh/annum, while the lowest was 212.50 kWh/annum.

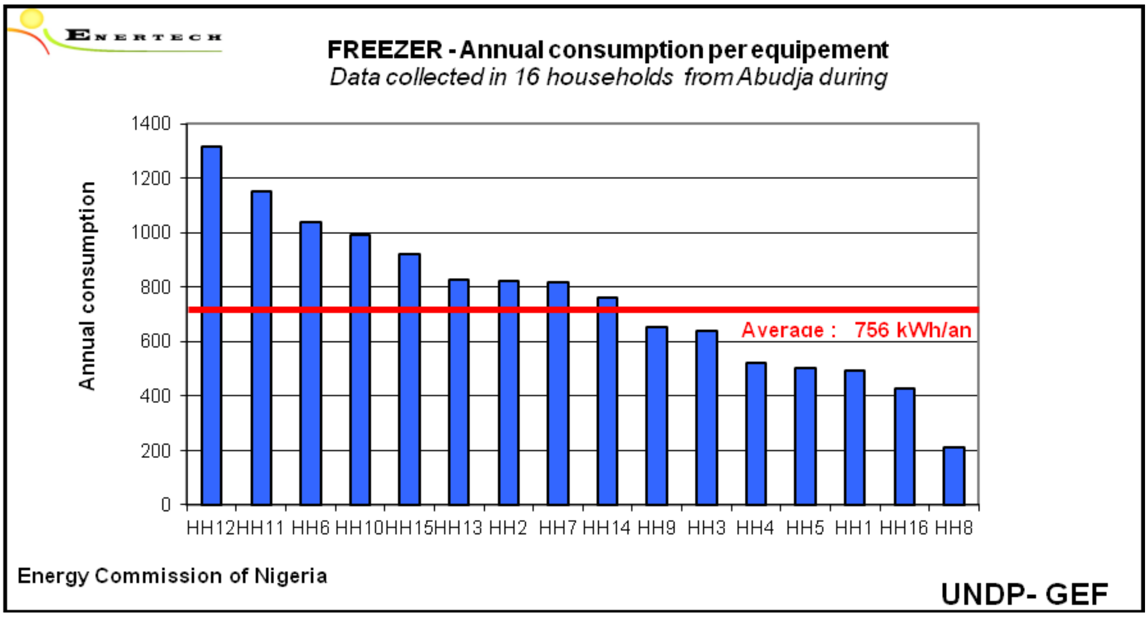

Fig. 5: Annual consumption of freezers monitored in Abuja

Sixteen (16) fridges were monitored during the study and the average annual consumption for was 420 kWh/annum; the highest reading was 941 kWh/annum and the lowest was 125 kWh/annum.

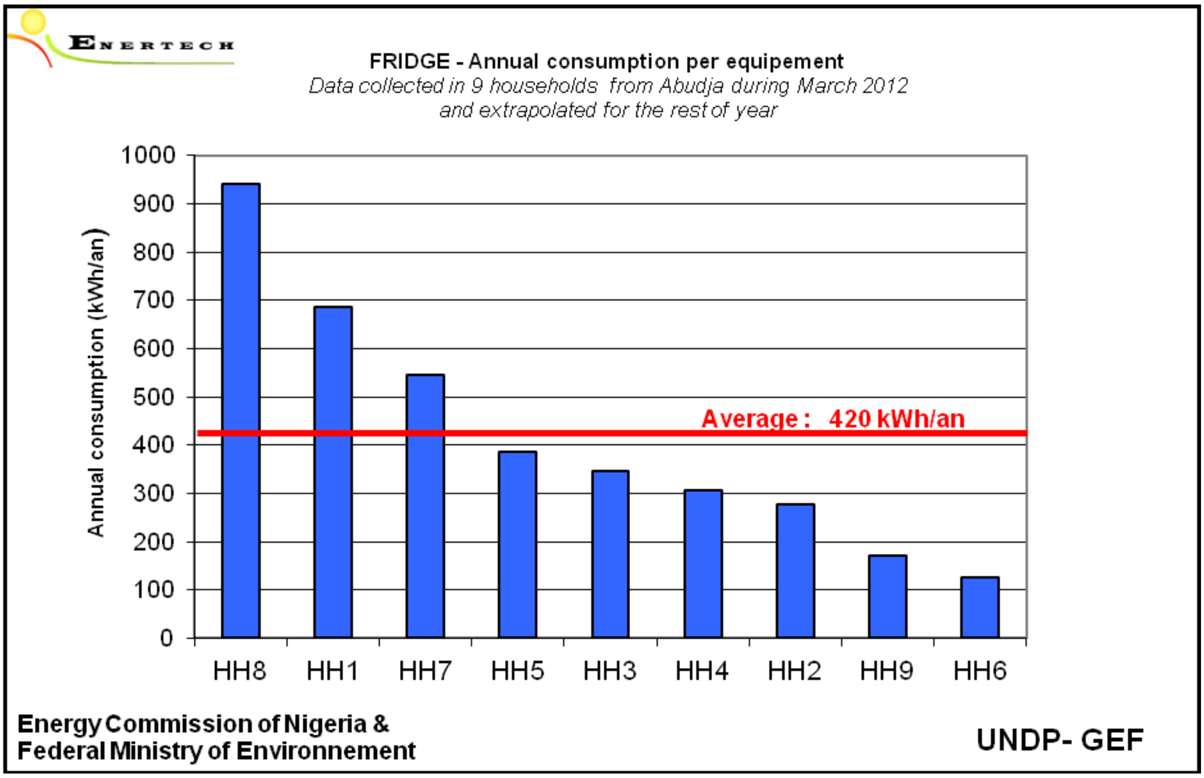

Fig 6: Annual consumption of fridges monitor in Abuja, Nigeria

Challenges and Lessons Learnt

The study in the Nigerian Federal Capital Territory revealed that the energy consumption of appliances is still very high compared to countries where effective energy efficiency measures had been put in place. Similar studies have been carried out in France (2007), Sweden (2007) and England (2011). Compared to these countries in, the average annual consumption of fridges, fridge-freezers and freezers in Nigeria is the highest. The lowest records were for these appliances were in England in 2011.

Table 1: Average annual consumption for Nigeria and European countries

	Annual consumption per equipment (kWh/an)		
	Fridge	Fridge-freezer	Freezer
FRANCE 2007	253	460	556
SWEDEN 2007	225	469	470
ENGLAND 2011	162	427	344
NIGERIA 2012	**420**	**698**	**756**

Table 1 above also revealed that the average annual consumption for cooling appliances in European countries decreases with time. From the study conducted in France in 2007, the average annual consumption of fridge, fridge-freezer and freezer were 253, 460 and 556 kWh/annum respectively. The study conducted in England in 2011 (about four years after the study in France) reveal a considerable fall in the annual energy consumption of domestic cold appliances. This may be as a result of several energy efficiency measures such as standard and label which have been introduced in many European countries. From the study in France (2007) and the study in England (2011), there was 36%, 7% and 38% decrease in average annual consumption for fridges, fridge-freezer and freezer respectively.

These preliminary study in Abuja (2012) compared to the study in England (2011) revealed that the average annual consumption recorded in the current study are significantly higher than that recorded in England (2011). For instance, the study revealed that the average annual energy consumption for fridge, fridge-freezer and freezer for Nigeria was 61%, 39% and 54% respectively higher compared to the study in England. This call for the need to embark on energy efficiency programmes in Nigeria. This further justifies the objective of the on-going UNDP GEF Nigeria Energy Efficiency Programme, on the need to introduce measures to promote energy efficiency in end-use appliances.

The on-going UNDP GEF project is positioned to transform the Nigerian market and lay the foundation for developing an energy efficient culture in Nigeria. To develop and implement an effective and efficiency standard and labelling programme will require collaboration between different agencies of government and stakeholders. For instance, the Standard Organization of Nigeria has the mandate within the national law to develop and enforce standards. The enforcement of appliance standards will not be possible without the involvement of the Nigerian Custom Services, having the mandate to protect the Nigerian border from substandard and unaccredited goods.

One of the challenges encountered so far in developing the S& L initiative in Nigeria was bringing all actors to the ‘table’ to pursue one course. To address this, the project implementation has adopted the bottom-top approach where the project activities were driven by stakeholders who will be directly affected by the policy. Through adequate consultation and capacity enhancement, the Project received the support and buy-in of state and non-state actors, most especially the central government in Nigeria; this has been a major achievement in this project. The Project Team aligned with relevant state and non-state actors to execute the various activities of the project.

CONCLUSION

These preliminary results has clearly demonstrated the benefits of using metering study for the monitoring of the electricity consumption of selected appliances in the households based on different income groups in Nigeria. The choice of equipment chosen did not only allow continuous monitoring but allowed huge amount of baseline data to be collected and stored. These baseline data are currently being analysed in detail and a full report will be available in September 2013. These results will subsequently be used for the designing of the MEPS for lighting, AC and refrigerators.

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Effects of Appliance Standby Electricity Consumption on Turkish Residential Electricity Sector

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Abstract

Turkey's rapidly growing population and economy have resulted in a rapidly growing demand for energy, especially for electricity. Currently, residential electricity consumption has the second highest share and accounts for about 25% of the national electricity consumption. The increase in residential electricity consumption is mainly due to the increase in household income levels and decrease in the costs of household appliances which resulted in a dramatic increase in appliance ownership in recent years. There is very limited number of studies on residential electricity consumption, and there is currently no study on residential end-use and specifically standby electricity consumption for Turkish households. Studies on standby electricity consumption conducted in many other countries show that standby electricity consumption accounts for about 7 to 15% of the total household electricity consumption. Thus, the objective of this study is to determine the standby electricity consumption of urban Turkish households, which is carried out by conducting surveys and standby power measurements at 260 households in Ankara, Turkey. Among 260 households, 1746 appliances with standby electricity consumption are determined and their standby powers are measured; and type, power, and hourly usage information of 3423 bulbs are gathered. The average household active appliance, standby appliance, and lighting electricity consumption and associated CO_2 emissions are estimated as 2448, 95, 209 kWh/year, and 1021, 45, and 100 kg CO_2/year, respectively. It was also found that standby electricity consumptions of the households accounts for about 4% of the total household electricity consumption, whereas active appliance and lighting end-uses account for 88 and 8% of the total, respectively.

Introduction

Research on determining the electricity consumption of household appliances that were either switched off or not performing their main function started in early 1990's [1,2,3]. Standby electricity consumption (SEC) is the best known and widely used term for this type of residential electricity end-use. Many more studies are later conducted to determine SEC consumption of various new and stock household appliances [4,5,6,7,8,9,10], amount of household and national SEC and/or standby power [11,12,13,14,15,16,17,18,19,20,21,22,23], and associated CO_2 emissions [21,24]. Due to the increasing trend in electricity consumption of standby end-use, many countries and non-governmental bodies have taken steps to reduce standby power of new appliances in the market, such as implementing appliance energy efficiency standards and labels [25,26,27,28,29,30,31,32]. The effects of these steps in reducing the household and national electricity consumption, electricity expenditures, and associated CO_2 emissions are also studied by many researchers [9,10,12,14,20,33,34].

The share of residential sector in total electricity consumption has been increasing and currently accounts for about one fourth of the total electricity consumption in Turkey. The residential electricity consumption was 1.0566 TWh and 14.5% of the total consumption in 1970 and increased by about 10% per year to 41.4107 TWh and became 24.1% of the total in 2010, whereas the national electricity consumption was increased by about 8% per year in this period [35].

Due to the significant increase in per capita income levels from €4805 in 1990 to €12,046 in 2010 [36] and decrease in the costs of household appliances; new appliance purchases have increased from 2.8 million in 2002 to 6.18 million in 2010 in Turkey [37]. As the number of appliances increases, the amount of electricity consumed by appliances at standby mode also increases. In a study that estimated the SEC of Turkish households using the bottom-up approach, Lebot et al. [24] assumed an average standby power of 10 W per household for Turkey for 1997. Also assuming that this standby electricity consumption is for 24 hours, the authors estimated that residential SEC accounts for 1.5% of the national electricity consumption in 1997. In another study conducted by International Energy Agency in 2001, the standby power estimate for Turkey is taken as 20 W, which increases the SEC share to 3% for 1997 [38]. Other than these studies, no other study has yet been conducted using either whole-house measurement or bottom-up approach to determine the amount and percentage of SEC for Turkish households.

In this study, the average standby power and electricity consumption of urban Turkish households are determined using whole-house measurements approach. Surveys and measurements are conducted at 260 homes in Ankara, the capital city of Turkey. The SEC fraction in the total household electricity consumption is also determined and compared with results of other whole-house measurements studies. These results are also extrapolated to the national urban housing stock to determine the reductions in national residential electricity consumption and total CO_2 emissions.

Methodology

Currently two approaches are used in determining the standby electricity consumption of the households, namely whole-house measurements approach or bottom-up estimates approach. The whole-house measurements approach mostly involves visiting a number of sample houses, conducting a detailed survey about appliances characteristics and occupant electricity consumption behavior, and measuring standby power of the appliances in the homes. The total household electricity consumption is calculated by using the data gathered while conducting the survey and billing data of the households. The standby power of the appliances determined from measurements is multiplied by the number of hours the appliances are left at standby mode, which was obtained from the surveys, to determine the SEC of the household. By using these information, the share of SEC to the total household electricity consumption is then determined.

Bottom-up estimates approach is used when detailed appliance saturation and appliance standby power data is available. In this approach, the appliance saturation data is multiplied by the average estimated appliance standby power and standby hours. This approach is mostly accurate for major appliances for which detailed saturation and power data are available; but not very accurate for minor appliances due to lack of saturation and power data , which actually constitute most of the SEC of the households [39].

The primary objective of this study is to determine average standby power and electricity consumption, and fraction of SEC to the total household electricity consumption for urban Turkish households using whole-house measurements approach. Thus, during house visits data on lighting and appliances of the household is documented, and all appliances with standby power are measured, where available (*i.e.* if the appliance is hard wired into the electrical system it is not measured, such as door bells, security alarms, intercoms, furnace/boilers fans). The standby power measurements are conducted with a true RMS power Extech 380803 power analyzer [40]. This is a dual range meter (0–200 and 200–2000 W) with 0.1 W resolution for the low range and 1 W resolution for the high range. The accuracy of the measurements is ±0.9% of reading + 0.4 W for the low range and ±0.9% of reading + 4 W. for the high range. The meter also has a built-in data logger, which can store up to 1012 readings during continuous data logging.

The standby power measurements of the appliances are conducted when the appliances are plugged to the power, not performing their main functions but can be activated or switched on by a remote control, can be performing some secondary function (e.g. could have a display or clock which is active in this mode), and in their lowest power consuming mode. This type of mode of the appliances is also called as “passive standby power” [41, 42].

The volunteer households for the whole-house measurements are identified mainly based on their household income levels, since income is the main contributor to the number of appliances owned by the home owners and the consumption levels of the occupants [49]. It is desired that the sample of this study would be a representative of the income distribution of the urban Turkish household stock so that the number of homes surveys in each income category will be similar. The other criterion is that these households do not use electricity for space heating. A survey with 45 questions and a section to tabulate the standby power measurements is prepared. The survey questions are prepared to get detailed information of the dwelling (house type, area, and ownership), occupants (income, age, education, gender, and “at home” profile), appliances (type, age, model, size, power, and usage) and lighting (power, number, type, and usage), consumption behavior (plug-off , turn off or leave the appliances at standby when not in use), and billing data.

In order to determine the total household electricity consumption, average electricity consumption of major household appliances are gathered from open literature based on their size, model, brand, age, *etc*. For example; the refrigerators are categorized based on their type (top or bottom freezer, single or two doors, etc.), volume, and age; and average annual electricity consumption for each category is determined from the web sites of local and international retailers and government agencies such as *Natural Resources of Canada* and *U.S. Federal Trade Commission*. The active appliance electricity consumption is calculated by summing the electricity consumption of all appliances in the household when they are performing their primary functions. The lighting electricity consumption of each household is determined by multiplying the power of each lamp with its usage (number of hours per day). Similar to the household lighting electricity consumption, SEC is determined by multiplying the standby power of appliance with the number of hours it is left at standby mode.

The total annual household electricity is then calculated by adding the lighting, active and standby appliance electricity consumptions. This estimated total annual electricity consumption determined using the survey and appliance consumption data is then compared with the billing data, where available.

The carbon emission factor for Turkey is taken as 476 kg CO_2/MWh, which is calculated by taking the fuel specific emission factors from [43] and 2011 electricity generation by primary energy resources data from Turkish Electricity Transmission Company [44]. The cost of electricity is calculated by using tariffs that were in use by April 2012 [45]. Detailed information on methodology of the study can be found in [46].

Results and Discussion

The results of the study are presented in two sections; namely appliance and household standby power and consumption statistics.

Appliance and Household Standby Power Statistics

A total of 1746 appliances with SEC are identified and measured in the surveyed 260 households which yields on average 6.7 appliances with standby power per household. The average standby power of various appliances measured at the surveyed households, appliance saturation levels (number of appliances in the surveyed homes divided by the number of surveyed homes) and average household standby power based on saturation levels are presented in Table 1.

Table 1. Appliance Average Standby Power, Saturation Level, and Household Standby Power Based on Saturation Level

Appliance	Average Standby Power, W	Saturation Level, %	Average Household Standby Power Based on Saturation Level, W
Satellite Receiver	7.7	106	8.1
CRT TV	4.8	154	7.4
Modem/Router	4.6	71	3.2
Plasma TV	4.3	9	0.4
Stereo Tape/ CD Player	3.6	27	1.0
Desktop PC	3.4	46	1.6
Home Audio System	3.2	23	0.7
Rechargeable Vacuum Cleaner	3.1	27	0.9
Laptop Computer	2.8	49	1.4
DVD, VCD Player	2.7	37	1.0
Printer/Scanner	2.6	18	0.5
Furnace Fan	2.6	44	1.1
Cordless Phone	2.4	64	1.5
Desktop PC Monitor	2.3	45	1.0
Water Cooler	2.3	4	0.1
Air Conditioner	2.1	3	0.1
Clothes Dryer	2.0	0	0.0
Dishwasher	2.0	7	0.1
Alarmed Clock	1.9	4	0.1
Radio	1.8	12	0.2
Oven	1.7	17	0.3
LCD TV	1.6	73	1.2
Game Console	1.6	4	0.1
Home Theater	1.5	4	0.1
Clothes Washer	1.5	8	0.1
Microwave Oven	1.3	8	0.1
LED TV	0.3	4	0.0
Total		-	32.2

As seen in this table, the satellite receivers have the highest average standby power values (7.7 W) and the CRT TV are the appliances with the highest saturation levels among the appliances measured in the surveyed homes. The average standby power for DVD players and receivers are found to be lower than the values stated in other studies [6,9,34,48], since DVD players are found in this survey were purchased by households in more recent years and exhibit lower standby power. The ranges of the standby power for the remaining appliances are similar to those reported in [6,15,17,34].

The average standby powers of the appliances are multiplied by the appliance saturation levels to determine the average household standby power. When these values are summed up, the average household standby power is calculated as 32.2 W, as presented in Table 1. This shows that the based on the saturation levels determined in this study, the average household standby power is 32.2 W.

The distribution of the household standby powers determined for 260 homes is presented in Figure 1. As seen here, the majority of the surveyed households have standby powers between 15 and 30 W, and the maximum value is 120 W. The geometric mean of this distribution is 22 W. As seen here and also based on Chi-squared and Kolmogorov–Smirnov tests, the distribution of these households presents a log-normal distribution. Thus, the average household standby power of these households can be taken as 22 W. The average household standby power was estimated as 20 W in a previous study conducted by IEA [38]. Thus, it shows that this estimate is close to the one estimated by EIA [38].

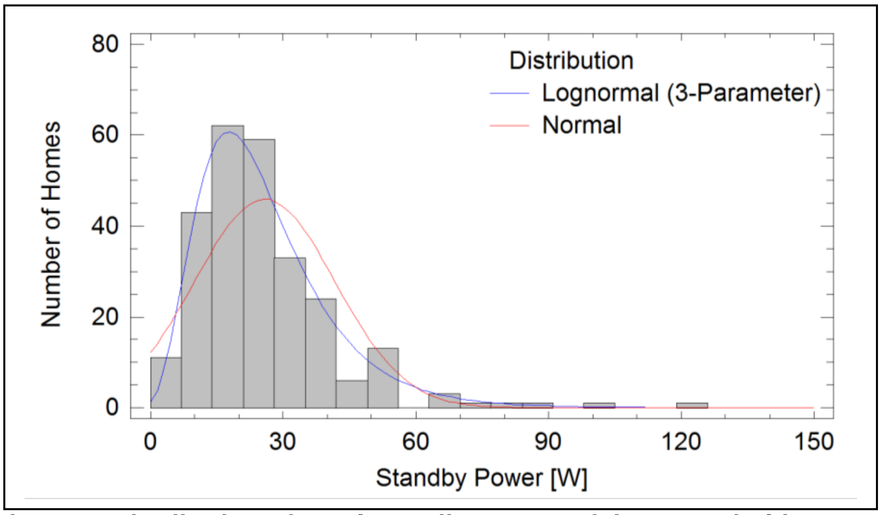

Figure 1. Distribution of Total Standby Power of the Households

The average household standby power and the number of surveyed in this study are presented together with the results of other studies based on whole-house approach in Figure 2. As seen in this figure, the average standby power estimated in this study presents one of the lowest values after the ones found for Romania and Argentina, where the household income levels are lower than the countries in which higher standby power results were obtained.

The whole-house measurement approach involves uncertainties mainly due to defining and measuring standby power. Each study has its own definition for standby power and conducts measurements based on the appliances that fit in their definition. Some studies included continuous and hard wired appliance standby loads, which resulted in higher estimate for the household standby power. In some studies, only major appliances are measured and smaller electronic appliances are ignored, which led to lower estimates of standby power [28], in addition to the effect of lower household income levels.

Among the appliances of which standby power measurements were conducted, 39% of them were used for entertainment, 20% used in kitchen, 20% used in home office, 10% used for communication, and 11% were used for other purposes.

Appliance and Household Standby Electricity Consumption Statistics

The factors that determine the amount of SEC of the homes are appliance standby power and saturation levels, and the amount of hours that these appliances are left at standby mode. As presented in the *Methodology* section, the SECs of the appliances are calculated by multiplying the appliances' standby powers and the numbers of hours the appliances are left at standby mode, which was obtained from the declaration of the occupants during the survey. Thus, the amount of hours the appliances left at standby mode is as important as the standby power of the appliances. The average number of hours of the various appliances left at standby mode, average appliance SECs, appliance saturation levels, and household SEC based on saturation levels are shown in Table 2.

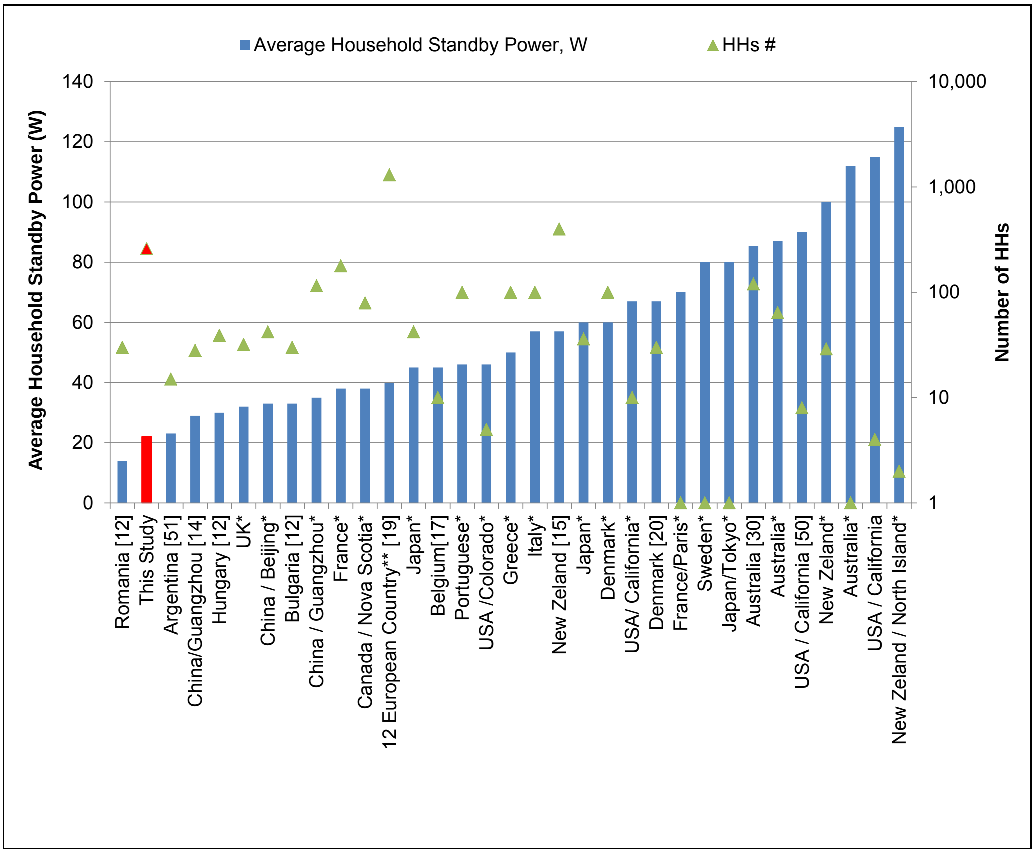

Figure 2. Household Standby Power (W) Results of Studies Based on Whole-house Measurement Approach

*Sources: [17,24,26,27,39]
**Belgium, Bulgaria, Czech Rep, Denmark, France, Germany, Greece, Hungary, Italy, Norway, Portugal, Romania

Based on the results presented in Table 2, the satellite receivers have the highest SEC in the surveyed homes, which also presented the highest standby powers. Their saturation level is second to that of CRT TV's. The SECs of the satellite receivers are found as 41 kWh/year, whereas their active electricity consumption is calculated as 38 kWh/year using the power and active usage hours data obtained during surveys. This shows that these appliances are left on standby more than they are actively used in a day and have very similar active and standby powers (2-3 W). Even though CRT TVs are one of the second highest standby powers, their SECs are not high due to their low standby usage (average 9 hours per day). This is probably because these old technology TVs are typically not the main TVs in the homes and have easy to reach on/off buttons. Thus the occupants can easily turn them off when not in use. Modems/routers have the second highest SEC among the appliances in the surveyed households with a saturation of 55%, and they are left on standby mode on average 16 hours per day. The average SECs of the appliances are multiplied by the appliance saturation levels to determine the average household SEC. When these values are summed up, the average household SEC is calculated as 156 kWh/year, as presented in Table 2. This shows that the based on the saturation levels determined in this study, the average household SEC is 156 kWh/year.

Table 2. Appliance Average Standby Power, Saturation Level, and Household Standby Power Based on Saturation Level

Appliance	Saturation Level, %	Avg. # Hours Appl. Left at Standby Mode, hours/day	Avg. SEC, kWh/year	Average Household SEC Based on Saturation Level, kWh/year
Satellite Receiver	106	15	41	43
Modem/Router	71	16	26	19
Rechargeable Vacuum Cleaner	27	21	23	6
Furnace Fan	44	23	21	9
Cordless Phone	64	23	20	13
Plasma TV	9	13	19	2
Game Console	4	19	19	1
Air Conditioner	3	24	18	1
Stereo Tape/ CD Player	27	15	18	5
Home Theater	23	18	18	4
Alarmed Clock	4	2	17	1
Water Cooler	4	16	16	1
CRT TV	154	9	16	24
Oven	17	23	14	2
Desktop PC	46	13	14	6
Printer/Scanner	18	13	12	2
Microwave Oven	8	24	11	1
Desktop PC Monitor	45	13	10	4
Radio	12	15	10	1
DVD, VCD Player	37	14	9	3
LCD TV	73	14	7	5
Laptop Computer	49	7	5	2
Home Audio System	4	9	5	0
Clothes Dryer	0	3	2	0
Dishwasher	7	2	2	0
Clothes Washer	8	4	2	0
LED TV	4	11	1	0
Total			376	156

The distribution of the household SECs determined for 260 homes is presented in Figure 3. As seen here, the majority of the surveyed households have SECs between 50 and 150 kWh/year, and the maximum value is 1180 kWh/year. The geometric mean of this distribution is 95 kWh/year. As seen here and also based on Chi-squared and Kolmogorov-Smirnov tests, the distribution of these households presents more of a log-normal distribution. Thus, the average household SEC of these homes can be taken as 95 kWh/year. Using the emission factor for Turkish electricity sector given in *Methodology* section, the CO_2 emission associated with SEC for an average household is calculated as 45 kg CO2 /year. The cost of SEC for an average Turkish household is calculated as 18 USD/year.

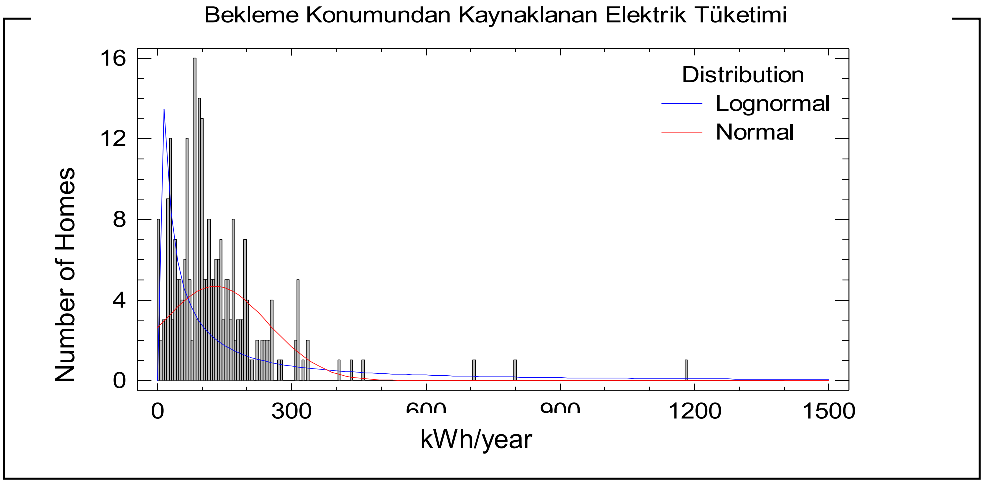

Figure 3. Distribution of Total SEC of the Households

The average household SEC and the number of surveyed homes in this study are presented together with the results of other studies based on whole-house approach in Figure 4. As seen in this figure, similar to average standby power results, the average SEC estimated in this study presents the lowest values after the SEC estimated for China [14]. The SEC results are low due to the electricity consumption habits of urban Turkish households. Most occupants of the surveyed household stated that they turn off or unplug their appliances when not in used for a safety measure to protect them against possible voltage fluctuations. This habit reduces the household SEC.

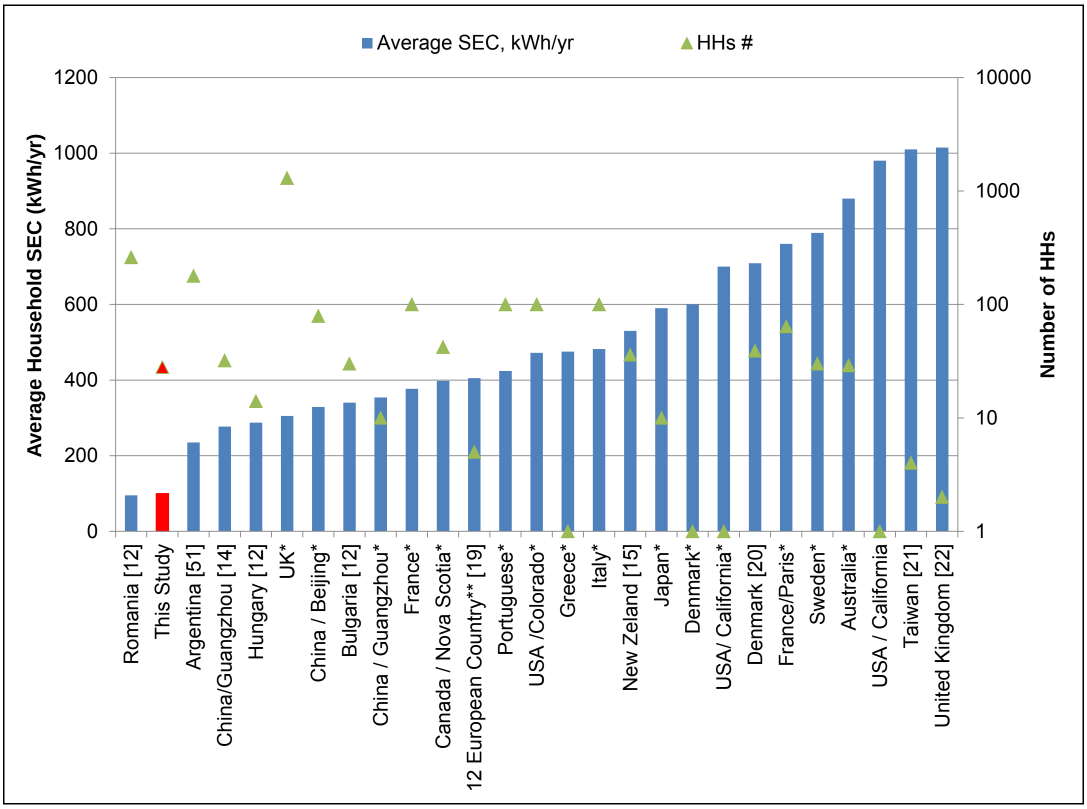

Figure 4. Household SEC (kWh/year) Results of Some Whole-house Measurement Studies

*Sources: [17,24,26,27,39]
**Belgium, Bulgaria, Czech Rep, Denmark, France, Germany, Greece, Hungary, Italy, Norway, Portugal, Romania

The lighting and active appliance end-uses are calculated for each household and summed with the SEC to determine the fraction of SEC in the total household electricity consumption. The average annual household end-use and total electricity consumptions, costs, CO_2 emissions, and their distributions are presented in Table 3. As seen here the average household SEC is 4% of the total household electricity consumption for the surveyed households.

Table 3. Appliance Average Standby Power, Saturation Level, and Household Standby Power Based on Saturation Level

End-use	Consumption, kWh/year	Cost, €/year	CO_2 Emissions, kg/year	Distribution, %
Standby	95	13	45	4
Lighting	209	29	100	8
Active	2144	295	1021	88
Total	2448	337	1166	

The number of urban households is determined as 22,278,548 in 2011 for Turkey [47]. Using the average SEC per household results, the amount of electricity and associated CO_2 emissions from the appliances left at standby at all urban households in Turkey can be estimated as 2116 GWh (5% of the total electricity consumed in Turkish residential sector in 2011 [35]) and 1003 thousand tons, respective (1% of the electricity generation associated CO_2 emission in 2009 [43]). The cost of this end use accounts for about 305 million € based on 2012 electricity tariffs in Turkey [44]. The amount of electricity estimated for standby end-use is very close to the amount of electricity generated in 2011 at Kangal Power Plant which uses lignite as fuel [44].

Conclusions

In this study, to the authors' knowledge for the first time, average standby power and SEC of urban Turkish households, and the fraction SEC in the total electricity consumption are determined using whole-house measurements approaches. The study is conducted by surveying 260 homes in Ankara, Turkey. A total of 1746 appliance standby power measurements are conducted, which makes about seven appliances with standby power per household. The satellite receiver was found to be the appliance with the highest average standby power and also SEC due to its high saturation and standby hours. The average total household standby power, SEC, and SEC fraction of the total household electricity consumption are determined as 22 W, 95 kWh/year, and 4%, respectively. The standby power found in this study is higher than the value estimated for Turkey [38], but lower than majority of the other national/regional values. It is difficult to compare the standby power and SEC estimates of the studies conducted using whole-house measurement approach since each study has its own standby definition and measurement protocol. The amount of electricity that is used by appliances left at for standby mode at urban households is estimated to account for almost 5% of the total electricity used in the residential sector in 2011 and close to the amount generated by a single lignite power plant.

Acknowledgement

This study is funded by The Scientific and Technological Research Council of Turkey (TUBITAK). The authors would like to acknowledge TUBITAK for their financial support.

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Encouraging public support for smart metering through demonstrating energy saving potential of appealing home energy management

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Abstract

Backed by raising energy demands, volatile oil prices and threat of climate change, smart metering is rapidly gaining momentum in Europe. Although considerations for large scale rollouts take place in many EU member states, public support and energy saving success should not be taken for granted. Smart meters only enable consumer satisfaction and energy efficiency if they come publicly undisputed and in the company of empowering energy feedback services. *This paper analyses the European progress on the implementation of smart metering and feedback services in general and elaborates in particular on the efforts in the Netherlands to win public support for smart meters and prove the energy saving potential.*

Following the United Kingdom (EDRP) and Ireland (CBT), the Netherlands is today the third EU-Member State to perform a set of large and scientific designed consumer live trials across the country involving more than 10000 households to deliver evidence for the energy saving potential of smart meters in combination with several kinds of innovative energy management systems and services. These trials will deliver input for the upcoming decision in Dutch parliament on how to proceed with the large scale rollout of smart meters between 2014 and 2020. *NL Agency will provide EEDAL 2013 participants a preview of the monitoring results of the trial programme and share practical lessons on the experience and expertise of relevant (market) actors.*

Introduction

Backed by rising energy demands and fears over security of supply and climate change, smart metering is rapidly gaining momentum across the world. Europe is expected to become a world leading centre of this development, thanks to the European Services Directive (ESD), Third Energy Package and Energy Efficiency Directive (EED). The 2006 Energy Services Directive laid the foundation for a European wide legislation for smart metering, by requiring individual energy meters and standards for frequent and understandable energy bills. The 2009 Third Energy Package accelerated the penetration of smart electricity metering in EU by setting a target of at least 80% of all households to have a smart meter by 2020, given a positive economic assessment. Finally, the 2012 Energy Efficiency Directive connected smart meters directly to dynamic pricing and improved feedback programs and strengthened smart meter and consumer feedback regulation.

Although considerations for large-scale smart meter rollouts take place in a growing number of Member States, public support and hypothesized energy savings should not be taken for granted. Experiences in the Netherlands demonstrate that smart metering can only contribute to increasing consumer involvement and enable effective household energy savings if smart meters are publicly accepted and accompanied by empowering energy management services. Without meeting such preconditions, rollout and energy efficiency prospects will be much more uncertain.

By elaborating on these experiences in the Netherlands, this paper could provide practical lessons for stakeholders from other Member States who also face public reluctance with the imposition of smart meters. Additionally, the solution adopted in the Netherlands to learn together with relevant stakeholders and subsequently arrive at better policy proposals that also acknowledge end-user needs and ensure more promising prospects for energy savings, could help other Member States to develop regulatory frameworks that are more likely contribute to consumer satisfaction and increased energy efficiency.

This paper starts with a brief introduction on smart metering and a short European wide overview of Member States where large-scale smart meter penetration are already underway or being considered. This overview is extracted from the new European Smart Metering Landscape Report (2nd ed.), a deliverable of the SmartRegions project. SmartRegions, funded by Intelligent Energy Europe, focuses on promoting innovative smart metering services, such as informative billing and feedback, variable tariffs and load control services that offer most potential to bring about energy savings and peak load reduction. The SmartRegions project aims to inspire and encourage energy utilities, energy service providers as well as law makers across Europe to initiate the development of effective smart metering policies and innovative smart metering services by:

1. Monitoring the smart metering landscape in European countries and giving recommendations for regulatory frameworks.

2. Defining best practices for innovative smart metering services by analyzing their economic, environmental and social costs and benefits.

3. Promoting best practices for innovative smart metering services and exemplary smart metering regions as models for other Member States and regions.

The new European Smart Metering Landscape is a comprehensive rollout report on smart meters and metering services in Europe, including in-depth country profiles of all EU Member States and Norway together with case studies of related services for consumer feedback and peak-load shifting[1].

The main section of the paper elaborates on the experiences in the Netherlands, associated with intense political discussions in the past and defining the most important causes. The paper concludes with a brief overview of the actual situation and the upcoming trend of performing national scientifically designed live trials to deliver evidence for the smart metering energy saving potential and ensure a more (cost-) effective rollout.

Smart metering characteristics and European overview

Traditional meters provide less than perfect information for both consumers and suppliers. Consumers are generally only aware of consumption on a monthly, or even annual, basis, unless they make time-consuming efforts to monitor the readings on their meters frequently. Also, most suppliers only know how much energy a household consumes after a manual meter read. In addition, difficulties arising from limited data accuracy may cause disputes over bills, thereby possibly also hindering switching between suppliers and limiting market competition.

Smart meters eliminate many of these issues for consumers and suppliers by adding two dynamic key features to the functionality of the static traditional meter:

1. Storage of accurate metering data at specified time intervals.

2. Two-way communication between the consumers' smart meters and the operating system of the network operator / supplier.

By integrating storage capacity and communication technology, the smart meter allows for a radical change in customer-utility relations. In conjunction with smart technology, utilities can adopt pre-pay or innovative time-of-use pricing plan options to incentivize customers to use power more wisely.

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1 The European Smart Metering Landscape Report can be downloaded free of charge from the project's website www.smartregions.net.

Smart meters also enable consumers to track their usage in real-time and better understand their power habits via in-home display units, web-based interfaces or both.

The benefits from a rollout of smart meters potentially fall to all actors:

1. To consumers in terms of more frequent and more accurate bills, (near) real-time information to enable household energy savings and facilitation of new energy services.

2. To suppliers in terms of more frequent and accurate information and reduced operational costs.

3. To network operators in terms of more efficient network operation and capacity control.

4. Finally, to society in terms of a better functioning energy market and reduced carbon emissions.

Smart meters also pave the way for smart grids, an allied tool to help utilities to balance loads across their electricity networks and help consumers to manage their energy demand more effectively. Smart grids integrate the actions of all users connected to an electricity power system, employing communications, innovative products and services, and intelligent monitoring and control technologies to:

1. Help utilities to efficiently manage the full array of power generation assets, including traditional generation facilities and renewable sources such as wind turbines, to meet customer needs.

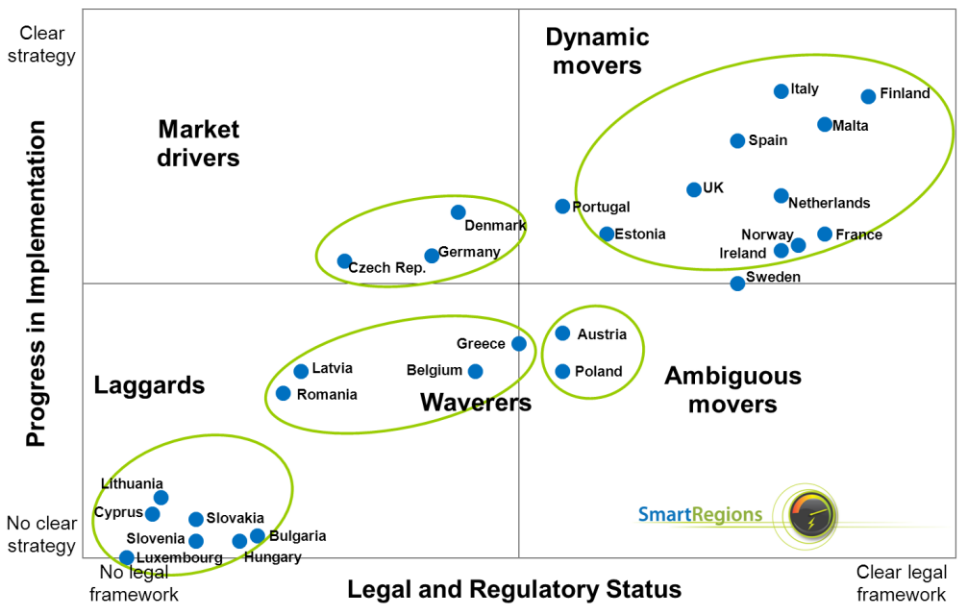
2. Provide consumers with more information about their own usage and peak demand so they can adjust their behaviour.

3. Reduce the environmental impact of power generation through incentivizing customers to reduce electricity use and/or shift electricity usage from peak to off-peak hours to avoid running costly fossil-fuelled peak generation units.

European overview

Due to legislation such as the Energy Services Directive and the 3rd Energy Package, a majority of the countries in Europe already have, or are about to implement a legal framework for the installation of smart meters. However, the topic continues to generate heated discussions in the individual EU member states. The Landscape Report 2012 depicts the developments in each country and shows the relative advance in respect of the topic of smart metering. These different approaches in the Member States are represented through the classification in the following categories: dynamic movers, market drivers, ambiguous movers, waverers, laggards.

Countries such as Estonia, Finland, France, Ireland, Italy, Malta, Netherlands, Norway, Portugal, the United Kingdom, Spain and Sweden are "dynamic movers". Most of them have already decided on a mandatory rollout with a specified timetable. "Market drivers" such as Germany, the Czech Republic and Denmark have not established legal requirements for a full rollout. There are the obligations for the introduction of smart metering only for a certain category of customers, e.g. in newly built houses and renovated houses. Nevertheless, utilities go ahead with the installation of smart meters either because of internal synergetic effects or because of customer demands. The situation in Austria and Poland can be characterized as “ambiguous”. Although significant progress is visible, there are still some important decisions lacking. In the countries called "waverers", first initiatives and pilot projects for the introduction of smart meters have been launched. In the "laggard" countries smart metering is not yet a focus. The following illustration provides an overview of the legal and regulatory situation and the implementation status in the EU countries and Norway.



Smart metering regulation in the Netherlands

The Netherlands is the first EU Member State to opt for a voluntary-based rollout of smart meters to obtain widespread consumer involvement and effective household energy management. In order to understand the argument for a voluntary-based rollout as an equally effective alternative for a mandated rollout, the course of events in the Netherlands will be chronologically presented and analyzed in more detail.

Chronological overview

In the Netherlands the smart meter rollout is part of a broader new energy market model for consumers and small business users. Apart from the desire to correct and avoid administrative problems following the liberalization of the Dutch energy market in 2004, other main drivers were to stimulate competition in the energy market, i.e. easy switching for consumers between suppliers, improve operational efficiency for market parties and support energy savings for end-use customers. Demand response related objectives, such as dynamic pricing to avoid peak loads, are not important because of the temperate climatic conditions. The Dutch tariff system is based primarily on fixed rates. Except for national reasons, the legal rollout was also designed to simultaneously meet the requirements of the European Energy End-use and Energy Services Directive (ESD).

The original plan: mandated rollout of smart meters.

In 2008, the Dutch government presented a first legislative proposal to bring the smart meter under the responsibility of network operators in the regulated domain in conjunction with a mandated rollout to all households. Following consultations in the market sector, the Ministry of Economic Affairs proposed the following meter market changes:

1. All small users will be given a smart meter.

2. The grid operators will be responsible for rollout. The grid operators will own and maintain the smart meter and be responsible for a total distribution.

3. The meters will become part of the regulated domain of the grid operator, being considered part of the physical infrastructure.

4. The cost of the hardware (meter rent) will be regulated.

5. The energy retailers will be responsible for all customer-related processes and metering data management.

6. The smart meters must comply with minimum functionality requirements and technology specifications to ensure cost-efficiency, interoperability.and consumer interests.

To meet the obligation arising from the above-mentioned ESD to provide regular feedback to consumers about energy consumption, the government stated a preference for setting a minimum frequency of 6 times per year (every two months).

The government proposed a mandated rollout as a prerequisite, because it was expected that a smart metering rollout in a liberalized market, without further regulation, would probably reach no more than about 30% penetration. In that case, several of the smart meter benefits mentioned above would not be realized.

The smart meter rollout will be partly funded from the current meter tariff. Also, the tariff will be stable in the first years of the rollout and will eventually be based on actual costs reduced by profits made in the first period. To date, the meter charge has not been regulated and has increased by up to 100% since 2001. The Dutch regulator (NMa) concluded in 2008 that there was no relation between the increased tariffs and actual costs and the meter costs should therefore be regulated.

In 2009, after an intense political debate, the Dutch Senate declined to approve a mandated rollout of smart meters because of privacy and security concerns. To solve the privacy issue, the mandatory rollout of smart meters was turned into a voluntary rollout. Furthermore, the revised proposal settled security concerns by introducing additional security guarantees.

Revised plan 2011: voluntary rollout of smart meters

In 2011 the Dutch parliament accepted a revised Electricity Act and the Gas Act, in which **network operators** (as the owners of the smart meters) are mandated to offer households and small businesses a smart meter with minimum functional and technical standards. Households and small businesses will have a legal choice to accept or refuse this meter. Legal customer options are:

1. The option to refuse the installation of a smart meter and keep the traditional meter.

2. The option to have a smart meter installed, or once it has been installed, the prerogative to opt out of sending meter readings automatically. As such, smart meter functions as a traditional meter, still requiring a meter reader.

3. The option to have a smart meter installed, with standard meter reading frequencies of which the most important are: final billing in case of switching energy supplier or moving house, once a year for annual billing and bi-monthly meter readings for additional energy advice in cost and consumption overviews.

4. The option to have a smart meter fitted, with full automatic smart meter reading.

The revised Dutch Electricity Act and the Gas Act also mandates **Energy suppliers** to provide consumers with bi-monthly cost and consumption overviews as a standard feedback service. Additional regulation has been developed to set out the minimum information requirements for these bi-monthly overviews. Providing consumers with more detailed smart metering feedback services for household energy management, such as displays and internet applications, are, however, considered to be a market responsibility without regulation. The customer is free to choose and authorize any commercial service provider offering (real-time) smart meter data services beyond the minimum regulated level. In order to give market players access to the measurement data, the network operators have set up uniform authorization and authentication procedures. These procedures ensure that individual measurement data is only used for the specific purposes for which the customer has given his or her consent.

With these legal revisions included, the national consumers' organizations and privacy campaigners expressed their contentment with the bill, assuring the freedom of choice for the consumer. After a two year delay, the Netherlands had a legal rollout scheme in place.

New cost-benefit analysis

The need to revise the legal proposal also required the Ministry of Economic Affairs to perform a recalculation of the original national cost-benefit analysis performed in 2005 regarding the business case for the introduction of smart meters in the Netherlands.[2] The two major changes that prompted a new cost-benefit analysis were:

1. The smart meter will only be read once every two months in the standard situation. Only if express and unequivocal permission has been obtained from the consumer a more detailed reading can be done. In the 2005 analysis, detailed reading was still the standard situation.

2. The consumer will have the option of refusing the smart meter. This means that the consumer in question will keep his or her traditional meter. In the case of new construction and renovations of houses and small buildings it is compulsory to install a smart meter, and there is no obligation to replace it with a traditional meter at the request of the consumer. In this case the consumer can have the smart meter treated like a traditional meter by registering it as "administratively off".

Considering a situation of almost 100% acceptance of the smart meter as well as almost 100% standard readings, the updated cost-benefit-analysis still showed a positive business case result of approximately EUR 770 million. The main benefits derive from the expected energy savings potential. Based on the analysis of previous national and international experiments and expert opinions, the average structural energy savings potentials are estimated at 3,2% for electricity and 3,7 for gas. Other beneficial items (in order of positive contribution) are savings on call centre costs, a lower cost level as a result of the market mechanism (increased switching) and savings in meter reading costs.

Two year experience phase: delivering proof for energy saving potential

Today, the Dutch smart meter rollout has started following a two-stage approach. From 2012 until 2014, a small-scale rollout is in place for experiential purposes. During the small-scale rollout, up to 500000 smart meters for electricity and gas will be installed in cases of regular meter replacements (e.g. depreciation), newly built houses, large scale renovations and on request by customers. Based on these experiences and learnings, the rollout will continue on a larger scale eventually offering every household and small business a smart meter. Despite the voluntary nature of the rollout, the target remains the same: the installation of a smart meter by at least 80% of households and small businesses by 2020, as mandated through the 3rd Energy Package.

Part of the small-scale experience phase is a set of large and scientifically designed consumer trials taking place across the country. Following similar national programs in the UK (EDRP) and Ireland (CBT), the Netherlands is now the third EU-Member State to perform such a series of consumer trials to deliver differentiated evidence for the energy efficiency potential of a wide range of smart metering-

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[2] Prior to the original proposed changes in the Electricity Act and the Gas Act, which included a mandated rollout of the smart meter, a thorough cost-benefit analysis was conducted in 2005. This cost-benefit analysis, performed by KEMA by order of SenterNovem (now Agentschap NL), resulted in an expected positive business case of approx. EUR 1.3 billion(SenterNovem, 2005).

based feedback methods to contribute to balanced decisions favouring the future rollout of smart meters. To date, the Dutch monitoring program covers the largest and statistically most robust smart metering behavioural trials conducted nationally and is expected to provide a wealth of information on the impact of smart metering-enabled feedback initiatives on Dutch electricity and gas consumers.

The monitoring program distinguishes a range of informational stimuli on energy consumption and associated costs for dual fuel meters.

Effect of cost and consumption overviews

On the one hand, the program will focus on the actual measurable reduction effects in customers' electricity and gas demand achievable through the use of smart meters in combination with bimonthly cost and consumption overviews. As mentioned earlier, Dutch energy suppliers are legally mandated to issue six cost and consumption overviews each year. The overviews will be required to give a comprehensive account of the customer's energy usage and associated costs. Part of this will be a comparison of the customer's consumption with the equivalent period in the previous year, and a comparison with the consumption of their peer group. These comparisons should be provided in graphical format where practical. This is similar to the informative billing requirements in the EU Energy Efficiency Directive (2006/ 73).

For monitoring the energy saving effect of the cost and consumption overviews, a representative sample of over 10000 anonymous residential electricity and gas consumers with smart meters throughout the country will be involved in the trial. A control group, made up of 300000 consumers with traditional meters will be included to ensure a balanced experimental trial design. Their energy consumption will also be recorded to enable comparisons with the households that have received interventions under the trial program.

Effects of additional information stimuli

On the other hand, trials are programmed to investigate the behavioural and reduction effects in customer electricity and gas demand through the use of smart meters in combination with additional (free market) monitoring and managements systems. These interventions include in-home displays, web-based information systems and community-based concepts. In total, over 1400 residential consumers throughout the country will participate in these metering services trials. The trial participants are also allocated across different population groups and connected to control groups to ensure a balanced experimental trial design. Although the relatively small trials are not fully representative, the program is expected to deliver relevant and fact-based information about the possible energy saving merits of smart metering services for residential (and SME) consumers in the Netherlands. The trials are also expected to help shed light on the relative attractiveness of various media, functional and design options for specific metering service concepts.

All trials in the national monitoring program will be performed by, or in cooperation with the largest Dutch network operators Liander, Enexis and Stedin (representing approximately 90% of all meter connections in the Netherlands). This takes place under the supervision of independent academic advisors who will statistically analyze the consumption data gathered from the trials to determine the customer response to the smart metering enabled measures tested in terms of the impact on their overall electricity and gas usage. Pre-trial and post-trial surveys will also be conducted to draw demographic, behavioural and experiential conclusions from the trials.

The monitoring program results will deliver input for parliamentary evaluation of the small-scale rollout towards the end of 2013. The statistical evidence from the trials will also provide relevant consumer information for the commercializing and/or the deployment of smart metering services by free market players.

Conclusions and learnings

The Netherlands is the first EU Member State to opt for a voluntary-based rollout of smart meters, after fierce opposition from consumers' organizations and privacy campaigners. Taking into account that government mandated rollouts are generally considered to be the preferential method to reap the benefits of smart metering, the question arises about the significance of the developments in the Netherlands for future rollout decisions in other Member States. How would a trend towards voluntary-based rollout schemes affect the economic and environmental advantages of widespread smart metering, as foreseen by the 3rd Energy package and EED?

This question is hard to answer at the moment, although similar discussions take place in other Member States. The occurrences in the Netherlands highlight the importance of a well-considered regulatory introduction of smart meters. Although more challenging, the Dutch pioneering route towards a voluntary rollout offers equally good prospects for a widespread rollout of smart meters and promising energy savings. However, a crucial factor for success in the first place will be close contact and collaboration with important stakeholders and opinion leaders in society to better meet end-user needs and agree on joint prospects for a widespread rollout of smart meters. Another factor of success is to provide evidence-based information related to actual, behavioural and attitude effects on household electricity and gas consumption following the simultaneous installation of smart meters and accompanying energy management services. Overall, it must be realized that a mandated rollout only ensures a full penetration of smart meters but does not guarantee successful consumer involvement and widespread energy savings.

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Detailed end-use metering of domestic appliances in Japan

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Abstract

Since the March 2011 Great East Japan Earthquake, nearly all Japan's nuclear power plants are shut down, making electricity saving measures urgent. However, there are not yet databases for evaluation of measures to decrease household appliance electricity demand. In 2012, the Ministry of Environment of Japan began both a questionnaire survey and an end-use metering survey. In this paper the breakdown of household electricity consumption in 56 households in the Tokyo area and in Hokkaido (a cold climate) is shown, based on results of the end-use metering survey over a 7-month period and a questionnaire about lighting usage. On average, for the metering period, understand 79% of overall usage in Tokyo can be accounted for and 87% in Hokkaido, including estimates for lighting.

For peak grid demand, for Tokyo summer daytime peak, air conditioning consumes the most, at 38%. Together with refrigerators and TVs, these three make up 70% of total demand. The Hokkaido winter daytime peak occurs in early evening, with no single appliance dominating the demand. For the six specified household electrical appliances with standard indicators for annual electricity consumption, metered results were compared with labeled values. Actual refrigerator unit electricity consumption (UEC) was 1.6 times the labeled value. For models after the 2006 revision of standard measurement conditions this difference shrunk, and both UEC and UEC per unit of internal volume tended to decrease. TVs and DVDs also exceeded their labeled UEC, while microwaves, rice cookers, and electric toilet seats consumed less than their labeled UEC.

Introduction

The Great East Japan Earthquake of March 2011 damaged many power plants in eastern Japan, leading to serious electricity shortages. In the summer of 2011, the Government of Japan, empowered by law, called for a 15% reduction in peak power demand by all large customers of Tokyo Electric Power Company (TEPCO) and Tohoku Electric Power Company. After that, due to concerns over the safety of nuclear power, nearly all Japan's nuclear power plants that shut down for scheduled maintenance were not restarted, so electricity saving measures expanded to all of Japan (except for Okinawa, where there are no nuclear power plants).

As of June 2013, unexpected or planned power outages have successfully been avoided through electricity saving measures. In planning electricity savings, it is vital to understand the structure of electricity demand. However, in Japan, while there were surveys for residential sector energy consumption (for example, see [1],[2]), existing data were insufficient to understand the structure of electricity demand. In particular, no database had been compiled for electricity demand by appliance type, and change in demand for each appliance by time of day (load curves), although results from past studies have been published sporadically in research reports and academic papers [3],[4]. For this reason, the electricity saving effects of measures sought by government and electric utility companies and implemented by businesses and residents could not be adequately predicted. In summer of 2011, measures with large impacts on service but relatively small saving effects (such as reducing the number of elevators in use) were widely carried out, causing a great burden on users. Of course, there were also businesses that could use effective monitoring data from building energy management systems (BEMS) already installed.

From before the Great East Japan Earthquake, opinion solidified that Japan should develop statistics similar to other countries, related to energy use for measures implemented as energy efficiency and climate change countermeasures. In the basic plan concerning the development of official statistics agreed on in 2009, it was specified to develop statistics that accurately grasp the CO_2 emission quantities of each sector. Therefore, from the fall of 2012, the Ministry of Environment began a test survey with the goal to develop statistics for the residential sector. The test survey is a questionnaire survey that provides an understanding of monthly energy consumption by energy source, but it cannot provide load information by type of appliance and time of use.

As shown in Figure 1, the proportion of household energy use held by lighting and appliances is high, so the need to understand its internal structure is significant. In order to do so, independently of the above mentioned questionnaire survey, the Ministry of Environment carried out an end-use metering survey relating to residential electricity demand, and for lighting equipment (for which it is difficult to measure electricity consumption) carried out a questionnaire survey about types of lights owned and conditions of their use.

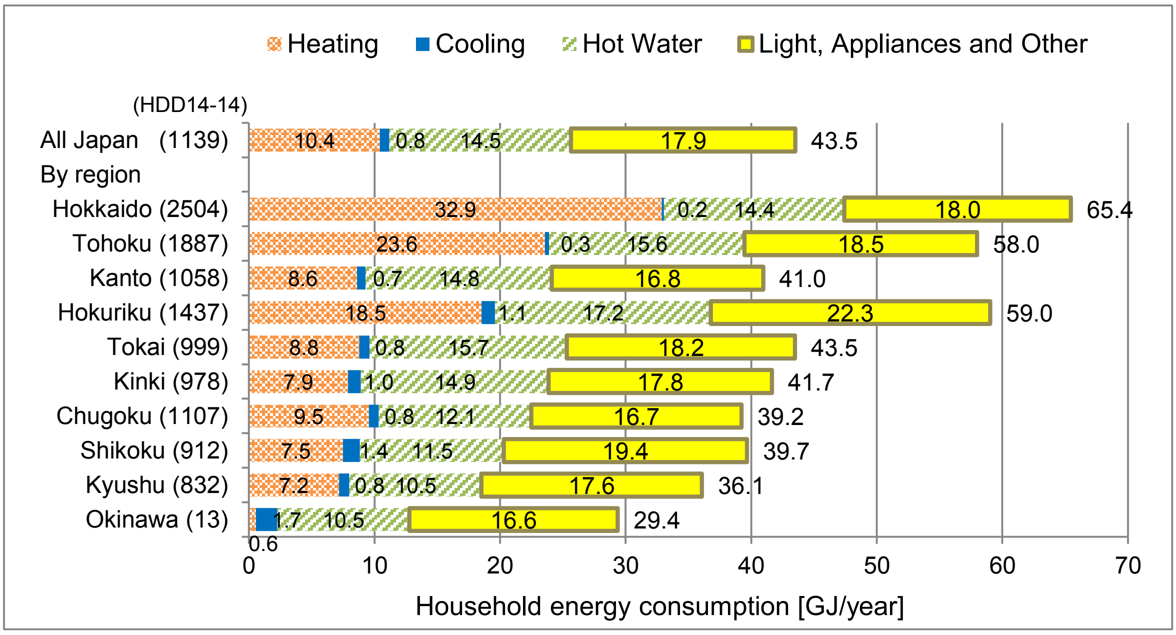

Figure 1: Household energy consumption by end-use in 2011

Source: Estimation by Jyukankyo Research Institute from Family Income and Expenditure Survey and other resources. Note 1: Value in parenthesis shows heating degree days (HDD14-14) of the region. Note 2: The heat conversion factor for electricity is 3.6MJ/kWh.

In this paper, we present breakdowns of residential electricity demand by appliance, based on results of the end-use metering survey and the lighting questionnaire survey. Results are shown for both overall electricity use, and for times when electricity savings are especially needed (times of grid peak demand). We also compare the label values for annual electricity consumption (based on energy efficiency standards) with the metered results.

Methodology

Profile of monitored households

Two regions were chosen for this study. One is Japan's most populous region, the Tokyo metropolitan area. The other is Hokkaido, which has a cold climate and different patterns of energy use than Tokyo.

The number of households studied by region, household type, and house type are shown in Table 1. In Tokyo, 36, and in Hokkaido 20 households were monitored. Targets for the distribution of house type were equal numbers of single-family detached houses and apartments. Targets for household type were singles and couples each at 20%, couples with children at 50%, and three-generation families at 10%. Participating households were chosen from those that applied via an online survey company's internet research panel, met the conditions for inclusion, and showed their intent to cooperate with the study. Excluded from consideration were the few households living in all electric houses, as well as those generating their own power (for example, by solar cells) due to concerns that the monitoring system could not be used correctly. Also, we note that the average number of personal computers per household was 1.9, which exceeds the average value in the March 2012 Monthly Consumer Confidence Survey of 1.1 by more than 70%.

Table 1: Number of monitored households

Household type	Tokyo metropolitan area		Hokkaido		Total
	Single-family detached house	Apartment house	Single-family detached house	Apartment house	
Single-person	2	5	0	4	11
Couple	4	3	2	2	11
Couple and children	10	9	5	5	29
Three-generation	3	0	2	0	5
Total	19	17	9	11	56

Note: This includes one replacement household for a family in the Tokyo area who quit the survey in December 2012.

Basic attributes of the monitored households are shown in Table 2. The average number of people per household is 2.64 in the Tokyo area and 2.85 in Hokkaido. This exceeds the average from the 2010 National Census of 2.26 for the Tokyo metropolitan area (for Tokyo, Kanagawa, Chiba, and Saitama) and 2.21 for Hokkaido. Similarly, the average floor areas of the monitored houses exceeded those from the 2010 Census (75 m^2 for the Tokyo area and 86 m^2 for Hokkaido). The average house age was 22 years for Tokyo and 16 years for Hokkaido. When compared to the 2008 Housing and Land Survey average age (21 years for Tokyo, 22 years for Hokkaido) we see that, on average, the houses in our Hokkaido study population are somewhat newer.

Table 2: Basic attributes of monitored households

Item	Tokyo metropolitan area	Hokkaido	Total
Average size of household [persons]	2.64	2.85	2.71
Average floor space [square meters]	82.0 (n=35)	97.2 (n=18)	87.2 (n=53)
Average of age of house [years]	22 (n=35)	16 (n=18)	20 (n=53)
Number of households	36	20	56

End-use metering survey

The monitoring study is planned for the one-year period from July 2012 to June 2013. The research in this paper describes an analysis performed using metering data through 17 February 2013. The targets of metering were electricity consumption of the whole house and of electrical appliances. Data other than electricity, such as room temperature, outdoor temperature, gas consumption, water consumption, were not collected.

Two types of power consumption meters were used. First, to measure power consumption for the whole house, a sensor was installed at the main circuit breaker at the house power distribution board. If a certain appliance had a dedicated distribution circuit (e.g. air conditioner) a sensor would also be installed in that circuit. Second, for appliances that could not be metered at the power distribution board, a small electric meter was installed between the power cord and the outlet. A total of 12 small meters were prepared for each household, and these were distributed according to numbers of appliances in the household, obtained from a preliminary questionnaire. The metering interval was 30 minutes. Metered data were automatically collected and transmitted over cell phone network or the internet.

Electricity use of the metering system is high enough that it cannot be ignored, so a fixed value is subtracted from the whole house value for each 30-minute measurement. Furthermore, although corrections due to air temperature were generally not made, to compare appliance label values from energy efficiency standards to metered results, temperature corrections were made in some cases.

Table 3 shows numbers of each appliance monitored in August 2012. All air conditioners in all participating households were metered. For other main appliances, such as refrigerators and TVs, more than 80% of units were metered. Appliances not metered included those with (1) no space in which to put the meter (for appliances like refrigerators and washers) or (2) in cases constrained by the number of meters per household, appliances expected to have low consumption (such as a TV in a bedroom, a router, a fan in Hokkaido). In winter, electricity used by heating appliances increases. Therefore, in autumn 2012, appliances chosen for metering were adjusted, from those only used in summer (e.g., electric fans) or those with small consumption, to heating appliances, not only including electric heaters and electric carpets, but also boilers and heaters mainly fueled by kerosene or gas.

Table 3: Quantity of metered appliances in August 2012

Appliance	Quantity of metered appliance [units]			Proportion of metered appliances to appliances in use	
	Tokyo metropolitan area	Hokkaido	Total	Tokyo metropolitan area	Hokkaido
Air conditioner	87	6	93	100%	100%
TV set	54	31	85	84%	82%
Refrigerator	37	20	57	97%	91%
Laundry machine	33	19	52	94%	90%
Microwave oven	34	18	52	92%	90%
Rice cooker	30	19	49	91%	95%
Electric toilet seats	32	16	48	89%	100%
Desktop PC	28	15	43	85%	100%
Notebook PC	24	17	41	62%	89%
DVD / Blu-ray recorder	26	12	38	63%	41%
Modem / Router	16	6	22	40%	30%
Electric fan	22	0	22	35%	0%
Air cleaner	11	4	15	69%	40%
Electric pot	8	6	14	40%	60%
Dishwasher	8	5	13	73%	71%
Other	32	39	71	-	-
Total	482	233	715	-	-

Note: There were 35 Tokyo area and 20 Hokkaido households participating in August 2012.

Questionnaire survey on lighting

Direct measurement of electricity consumption of lighting equipment was outside the scope of the end-use metering survey, but lighting was expected to use a high percentage of overall electricity. There are various methods to understand lighting electricity usage. Besides direct measurement, other methods involve measuring lighting intensity or lamp temperature and estimating electricity consumption. All these methods are expensive and difficult for occupants to cooperate. For this work, we investigated essentially all lighting equipment in use, using a questionnaire survey regarding kinds of lighting (incandescent, fluorescent, LED), lamp wattage, and average hours of illumination. From those results values for lighting electricity usage were estimated. The questionnaire period was October 2012. For future research, it would be good to validate the accuracy of this method.

Results

Breakdown of residential electricity consumption

Results of the lighting questionnaire survey and estimated values of electricity consumption are shown in Tables 4 and 5. Average consumption per lighting appliance of a Tokyo area household was 0.11 kWh/day. With an average of 13.9 lights, the average household was estimated to use 1.5 kWh/day for lighting. The average Hokkaido household used 1.6 kWh/day for lighting. Electricity consumption by incandescent lamps made up 22% and 16% of total lighting electricity usage in the Tokyo area and Hokkaido, respectively.

Table 4: Lighting appliance power consumption, hours used, and estimated daily UEC

Area	Type of lamp	Consumed power [W/unit]	Hour of use [h/day/unit]	Unit electricity consumption [kWh/unit/day]	N [unit]
Tokyo metropolitan area	Incandescent lamp	52	1.4	0.08	114
	Fluorescent lamp	43	2.5	0.12	200
	LED lamp	15	3.6	0.07	35
	Complex or unknown	89	2.7	0.19	7
	average, total	44	2.3	0.11	356
Hokkaido area	Incandescent lamp	51	1.0	0.06	83
	Fluorescent lamp	49	2.6	0.13	168
	LED lamp	11	2.4	0.03	15
	Complex or unknown	48	4.8	0.29	3
	average, total	47	2.1	0.10	269

Note: Results of the questionnaire survey, including valid responses only.

Table 5: Numbers of lighting appliances used and estimated daily electricity consumption

	Number of units		Daily electricity consumption	
	Tokyo metropolitan area	Hokkaido area	Tokyo metropolitan area	Hokkaido area
Type of lamp	[units/household]		[kWh/day/household]	
Incandescent lamp	4.2	4.6	0.32	0.26
Fluorescent lamp	7.0	9.3	0.87	1.21
LED lamp	1.9	1.0	0.14	0.02
Complex or unknown	0.8	0.4	0.14	0.10
total	13.9	15.2	1.47	1.57
Number of households	36	20	36	20

Note: These results are estimated from the lighting questionnaire survey.

Figure 2 shows the average electricity consumption per household from August 2012 to January 2013 for Tokyo metropolitan area households. In summer, electricity consumption rose, mainly due to air conditioning, while in winter it rose due to air conditioners (in heating mode) and other heating appliances, electric toilet seats, etc. Refrigerator electricity consumption was nearly twice as high in August as in January. TV electricity consumption showed essentially no seasonal change. Lighting electricity consumption based on the questionnaire survey was estimated at 1.5 kWh/day per household in October 2012. While lighting electricity consumption is expected to have seasonal changes, these were not measured as part of this study. Note that the category, "Other", includes consumption by unmetered refrigerators, TVs and lighting (except for October and for the annual average, when the estimated value for lighting is subtracted based on the October 2012 estimated values). "Other" consumption increased in winter, which may be due to some heating appliances and lighting not being metered.

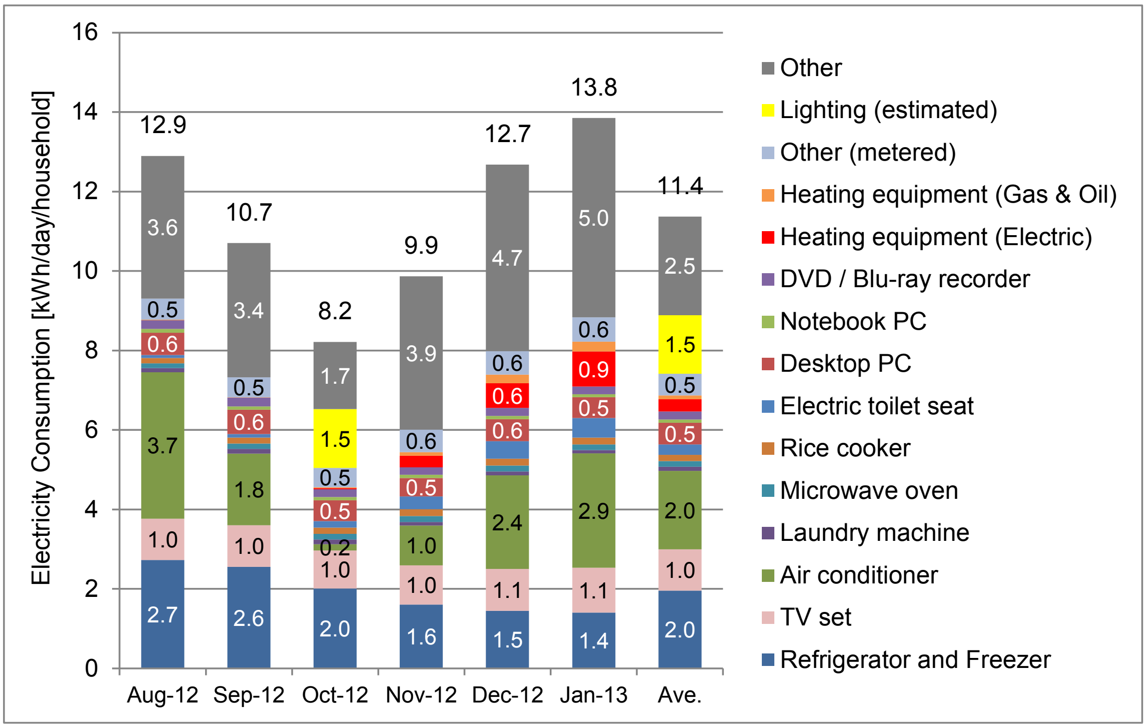

Figure 2: Monthly electricity consumption by appliance in the Tokyo metropolitan area

Figure 3 shows the average electricity consumption per household over the same period for households in Hokkaido. There is hardly any demand for cooling so summer and fall consumption is nearly the same. Compared to the Tokyo area, heating demand in Hokkaido is very high, but kerosene heating appliances are predominant, so the increase in electricity consumption is not as great as that of Tokyo. Electricity consumption to operate gas and oil heating appliances exceeds electricity consumption by electric heating appliances.

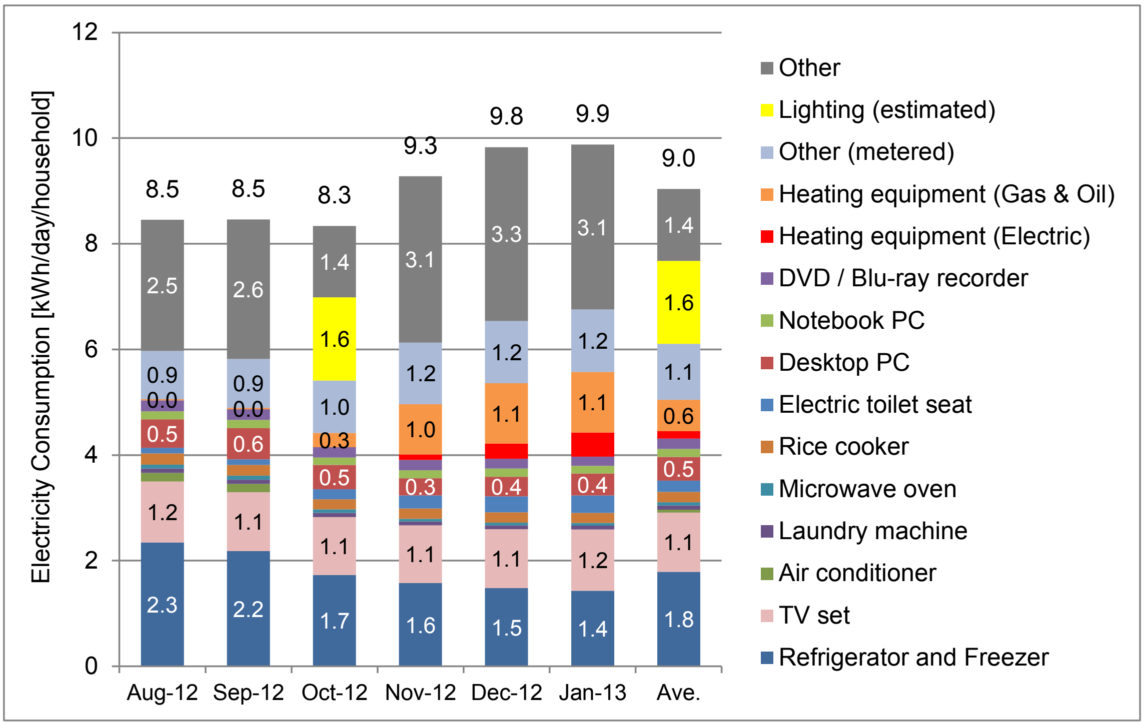

Figure 3: Monthly electricity consumption by appliance in Hokkaido

Figure 4 shows the relative contribution of each electrical appliance to total household electrical consumption for both regions. The breakdown of consumption that can be understood from the end-use metering survey is on average 65% for the Tokyo metropolitan area and 68% for Hokkaido. On average during the measurement period, for Tokyo, refrigerators and AC both used 17%, lighting was estimated at 13%, and TVs used 9%. For Hokkaido, refrigerators used 20%, lighting was estimated at 17%, TVs and electric components of gas and oil heating appliances each used 12%. The remainder ("Other"), which was not sub-metered and not estimated as lighting use, made up 22% for Tokyo and 15% for Hokkaido.

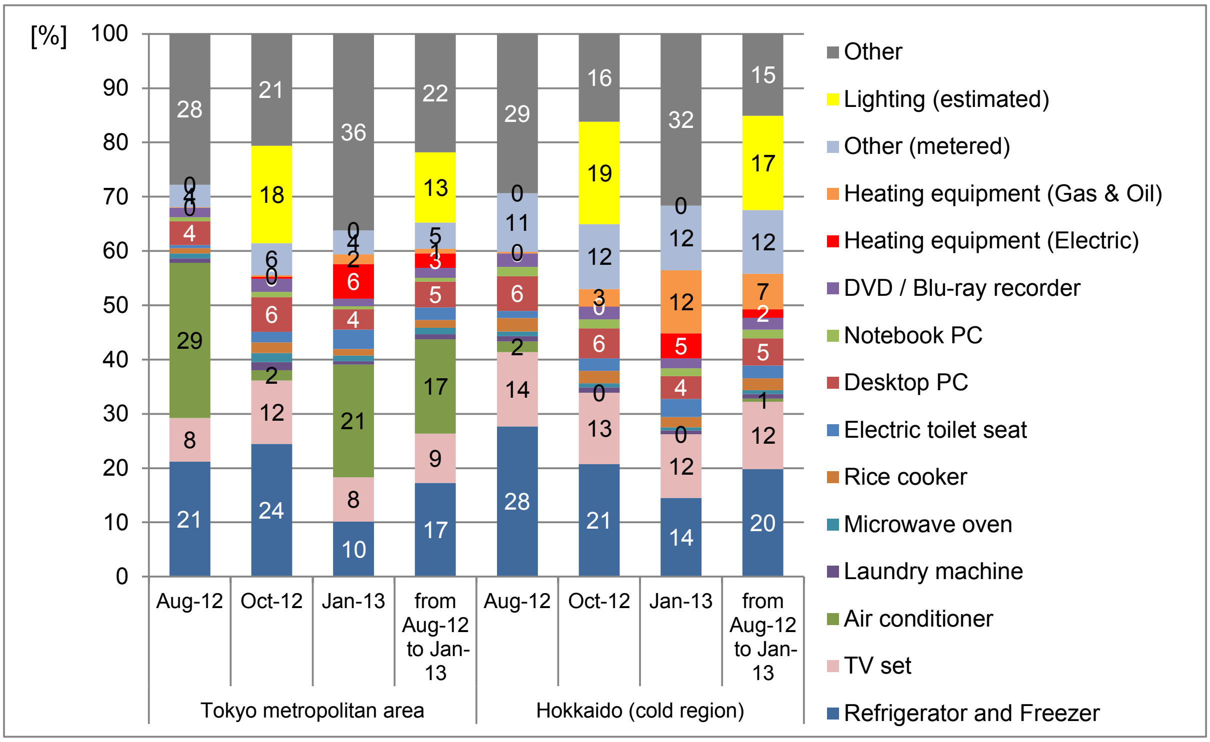

Figure 4: Composition of electricity consumption by appliance

Note: As explained in the text, lighting was estimated only for October 2012.

Breakdown of residential electricity consumption in grid peak hours

Based on the half-hourly metered values, the electricity consumption breakdown for each appliance for the survey households during grid peak hours was investigated. For the Tokyo area, TEPCO's top three daily peak demand days during summer 2012 were considered. For Hokkaido, Hokkaido Electric Power Company's (HEPCO) top three daily peak demand days during the winter of 2012-2013 were considered. There is a direct relation between grid power demand and outdoor temperature, so these peak demand days were extremely hot in the Tokyo metropolitan area and extremely cold in Hokkaido.

Figures 5 and 6 show the electricity consumption averaged over the three peak days by appliance for each half hour period, in both regions. On very hot days in the Tokyo area, air conditioner electricity consumption is high, can be seen throughout the day, and is particularly high between 8 pm and midnight. Refrigerator electricity consumption stays roughly constant at about 0.12 to 0.13 kWh/h. On very cold days in Hokkaido, daily electricity consumption of heating appliances (gas and kerosene, mostly kerosene) is about the same as that of refrigerators and TVs. During the grid peak hours of 17:00 to 19:00 they hold the third largest share of consumption, behind refrigerators and TVs. Refrigerator consumption is roughly constant at about 0.06 kWh/h.

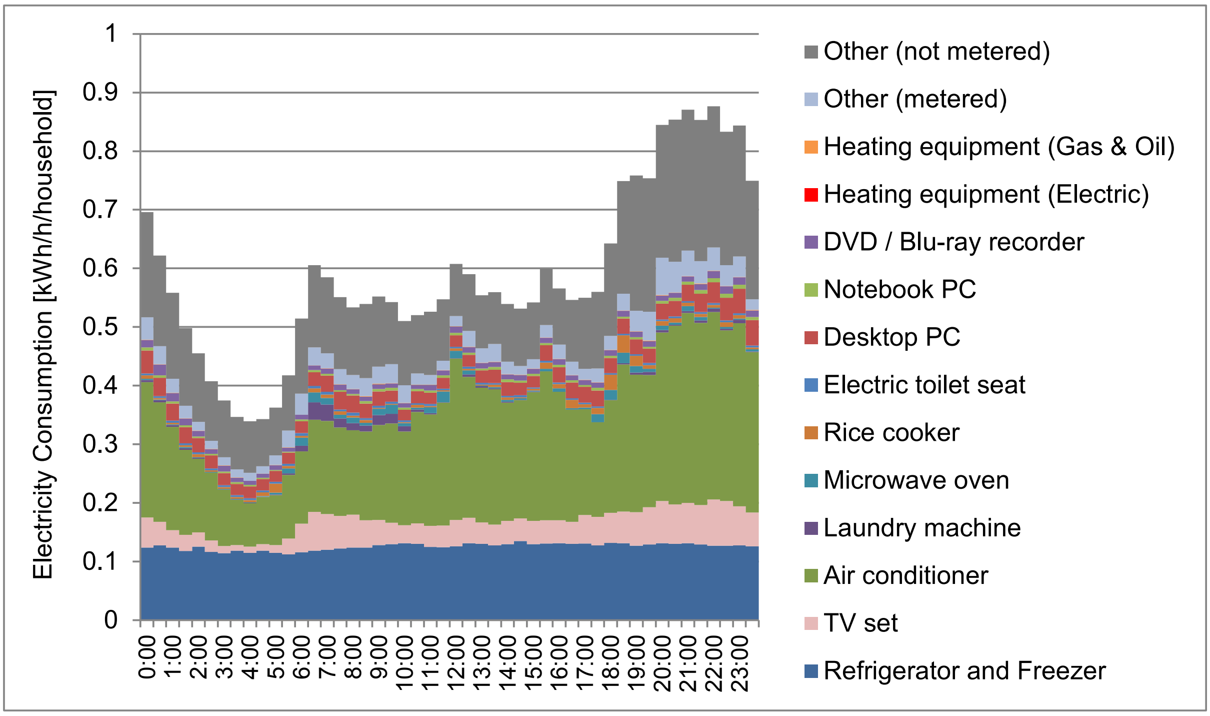

Figure 5: Half hourly electricity consumption by appliance on hot days in the Tokyo metropolitan area

Note: The days aggregated are TEPCO's top three daily peak demand days for summer 2012 (7/27/2012, 8/23/2012, 8/30/2012).

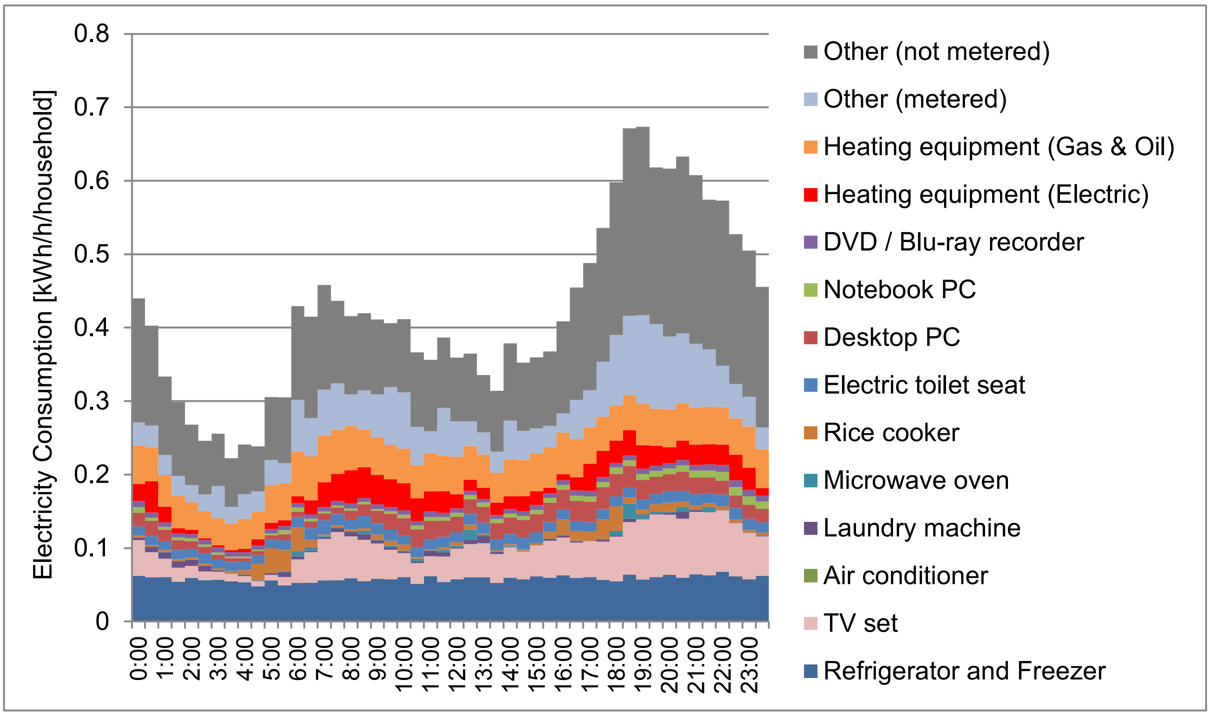

Figure 6: Half hourly electricity consumption by appliance on cold days in Hokkaido

Note: The days aggregated are HEPCO's top three daily peak demand days for winter 2012-2013 (12/26/2012, 12/27/2012, 1/18/2013).

Figure 7 shows the composition of household electricity consumption during grid peak hours for the two regions. Peak hours in the Tokyo metropolitan area are 14:00-15:00. At this time, the breakdown of electricity consumption is AC 38%, refrigerator 25%, and TV 7%. These three appliances make up 70% of consumption. Therefore, AC and refrigerator control measures are important for curbing peak demand. Peak hours in Hokkaido are 17:00-19:00, and compared to Tokyo's summer peak, the composition of electricity usage is diverse. "Other" is a significant 36%, which is probably due to the overlap of lighting hours with peak hours. Also, HEPCO's power demand on extremely cold days stays at a high level all day, with demand during the early morning (3 to 4 am) and morning (9 to 10 am) varying only about 1% from the peak demand. This is influenced by the demand of electric thermal storage heaters, electric tank water heaters, and also electric snow melting systems, operating in early morning hours. Note that households with such appliances were excluded from this study. Overnight, refrigerators and gas and oil heating equipment make up 38% of total electricity consumption (Table 6, so control of these appliances would be effective in reducing peak demand.

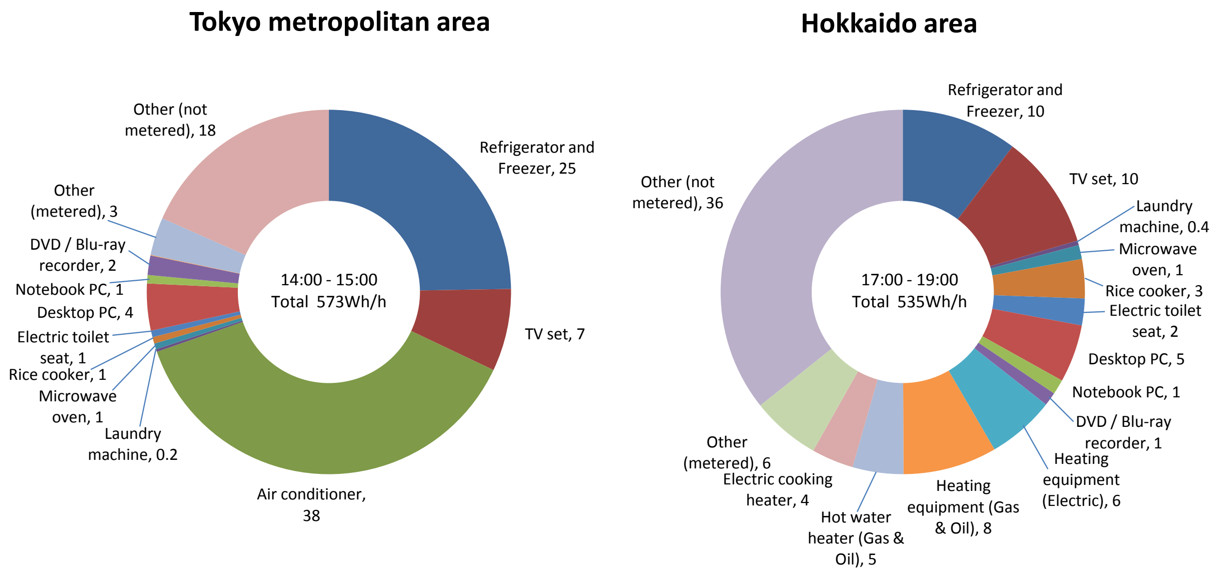

Figure 7: Composition of electricity consumption in grid peak hours

Note: Days aggregated are the same as those in Figures 5 and 6.

Table 6: Composition of electricity consumption in grid peak hours in Hokkaido

	Refrigerator and Freezer	TV set	Heating equipment (Gas & Oil)	Grid Demand [MW]
3:00-4:00	23%	5%	15%	5377
9:00-10:00	14%	11%	12%	5401
17:00-19:00	10%	10%	8%	5445

Note: Days aggregated are the same as those in Figure 6.

Comparison with labeled unit energy consumption (UEC)

In Japan there are energy efficiency standards for major household appliances. For air conditioners the energy efficiency indicator is the annual performance factor (APF), which compounds the coefficient of performance (COP) for heating and cooling, but it is very difficult to measure the APF under conditions of actual use. In contrast, for appliances such as refrigerators, for which the energy efficiency indicator is set as annual electricity consumption, through the end-use metering survey it is possible to understand the efficiency of appliances under conditions of actual use, and examine the validity of the labeled UEC.

The standard, JIS C 9801, specifying measurement conditions for determining refrigerator energy efficiency (annual electricity consumption) was revised in 2006. The catalyst for the revision was that a large difference had been seen between the labeled values and the results of metering under conditions of actual use [5]. End-use metering can be effective in validating measurement conditions related to energy efficiency standards.

Besides refrigerators (including freezers), other appliances in Japan with standard energy efficiency indicator of annual electricity consumption are TVs, DVD recorders (including Blu-ray), microwave ovens, rice cookers, and electric toilet seats. Below, the results from this end-use metering survey are compared with the labeled values based on energy efficiency standards.

Refrigerators and freezers

Refrigerator electricity consumption is highly correlated with ambient temperature, but temperature was not measured in this study. Figure 8 shows a comparison of the temperature at the regional Local Meteorological Observatory and refrigerator electricity consumption. The inflection point in the vicinity of 15°C for Hokkaido is due to the room temperature not decreasing as much as with outdoor temperature past that point. Also, the observation that at temperatures below about 20°C refrigerators in Hokkaido use more electricity than those in Tokyo can be explained since the temperatures in rooms with refrigerators (mainly kitchens) are lower in Tokyo than in Hokkaido.

For this analysis data from 1 July 2012 to 17 February 2013 were used, which includes metered results for three seasons. Although this is acceptable for obtaining an average value, for each refrigerator a piecewise linear function for electricity consumption as a function of temperature was generated, and then temperature data for a normal year were used to calculate temperature-adjusted annual electricity consumption.

Table 7 shows the temperature-adjusted actual unit electricity consumption (UEC) and the labeled UEC. The overall average actual UEC is 613 kWh/year, which is 1.6 times the labeled UEC. When broken down according to refrigerator model year, the ratio of actual to labeled UEC was 3.0 for products from 2003 to 2005--a bigger difference than for other years. This result is consistent with previous research [5]. After the 2006 revision of JIS C 9801 governing test measurement conditions for refrigerators, the ratio for units made in 2006 to 2008 decreased to 1.2, and for units made in 2009 or later the ratio stayed at 1.4. The actual UEC for units made in 2009 or later was 443 kWh/year, which is 37% lower than that of the 2003 to 2005 group. Also, the actual UEC per unit rated volume was lower for newer refrigerator models at 1.2 kWh/L-year for units made in 2009 or later, a decrease to about half the level of pre-1999 refrigerators. Therefore, it is evident that refrigerator energy efficiency has greatly improved in recent years.

Table 7: Comparison of actual and labeled electricity consumption of refrigerators and freezers

Year of production	Actual UEC (temperature adjusted) [kWh/year] [a]	Labeled UEC [kWh/year] [b]	Rated volume [L] [c]	Ratio of actual to labeled [a]/[b]	Actual UEC per rated volume [kWh/L/year] [a]/[c]	N
until 1998	704	445	284	1.6	2.5	12
1999-2002	644	406	347	1.6	1.9	10
2003-2005	704	233	394	3.0	1.8	10
2006-2008	590	487	357	1.2	1.7	13
since 2009	443	316	382	1.4	1.2	12
All	613	383	352	1.6	1.7	57

Note 1: UEC is unit electricity consumption. Note 2: Actual UEC (temperature adjusted) is calculated for each refrigerator using the observed relationship between outdoor temperature and that refrigerator's electricity consumption, using temperature data for a normal climate year to calculate temperature-adjusted annual electricity consumption. Note 3: Labeled UEC standard measurement conditions were revised in 1994, 1999, and 2006.

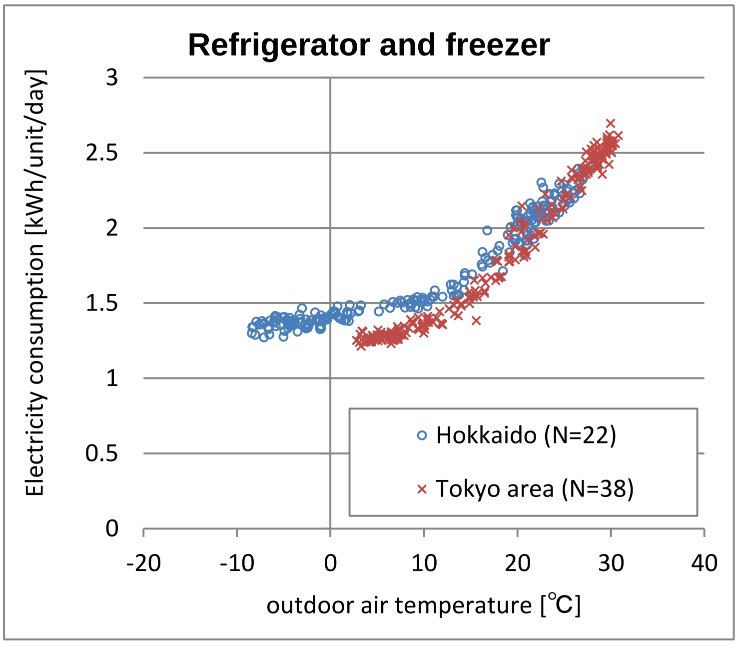

Figure 8: Daily electricity consumption of refrigerator and freezer versus outdoor air temperature

Note1: The metering period is from 1 July 2012 to 17 February 2013. N varies, depending on the day. Note 2: Outdoor air temperature is the Meteorological Observatory's observed value. For the Tokyo metropolitan area it is Tokyo and for Hokkaido, it is Sapporo.

TV sets

Table 6 shows the comparison results for TV sets. The TV labeled UEC assumes 4.5 h/day of use. Because TVs in living rooms were used a lengthy 7.3 h/day, the actual UEC exceeded the labeled UEC by a factor of 2.3. TVs in other places, such as bedrooms, were used relatively briefly, so the ratio of actual to labeled UEC was lower, at 1.3. For each TV set, a usage adjusted UEC was calculated by multiplying the actual UEC by the ratio of standard (4.5 h) to actual usage hours. The average usage adjusted actual UEC was 182 kWh/year, exceeding the labeled UEC by a factor of 1.5. A detailed examination of the reasons for this gap is needed, but it is possible that it arises due to differences in modes of use, such as screen brightness.

Table 8: Comparison of actual and labeled electricity consumption of TV sets

Place	Actual UEC [kWh/year] [a]	Actual UEC (usage adjusted) [kWh/year] [b]	Labeled UEC [kWh/year] [c]	Hour of use [h/day]	Display size [inch]	Ratio of actual to labeled [a]/[c]	Ratio of actual (adjusted) to labeled [b]/[c]	N
Living room	314	197	137	7.3	36	2.3	1.4	48
Other	124	146	94	4.2	26	1.3	1.6	20
All	258	182	124	6.4	33	2.1	1.5	68

Note 1: UEC is unit electricity consumption. Note 2: Actual UEC (usage adjusted) is calculated for each TV set, adjusting its usage to the standard (4.5 h/day) used for the labeled UEC.

DVD recorders

As shown in Table 7, the ratio of actual UEC to labeled UEC for DVD recorders (including Blu-ray) was 2.7 on average. To identify the time of use from the electricity consumption level is more difficult than for TV sets, so time in use was not added up. For recorders that had particularly big differences between actual and labeled UEC, a trend to exceed 10 W of minimum power consumption was seen.

The labeled UEC is calculated using the mode in which standby power is small, but it is likely that in these households, occupants set their recorders for the mode in which standby power is more significant, in order to shorten the wait time during start-up.

Table 9: Comparison of actual and labeled electricity consumption of DVD/Blu-ray recorders

Average of daily minimum power	Actual UEC [kWh/year] [a]	Labeled UEC [kWh/year] [b]	Ratio of actual to labeled [a]/[b]	N
Above 10 Watt	255	54	4.7	6
10 Watt or below	87	44	2.0	20
All	125	46	2.7	26

Note 1: UEC is unit electricity consumption.

Other

Results of comparisons for microwave ovens, rice cookers and electric toilet seats, together with the other three appliances are summarized in Table 8. The actual UEC was less than the labeled UEC for microwave ovens, rice cookers and electric toilet seats. However, the difference was not statistically significant for rice cookers. The standard measurement conditions for these three appliances have been set in detail based on survey results of actual conditions of use (such as environmental conditions and frequency of use), and it is possible that the circumstances of use of these microwave ovens and electric toilet seats differed from the standard assumptions.

Table 10: Comparison of actual and labeled electricity consumption of appliances

	Actual UEC [kWh/year] [a]	Labeled UEC [kWh/year] [b]	Ratio of actual to labeled [a]/[b]	N	Significant difference
Refrigerator and freezer	613	383	1.6	57	***
TV set	182	124	1.5	68	***
DVD / Blu-ray recorder	125	46	2.7	26	***
Microwave oven	46	71	0.66	21	***
Rice cooker	80	96	0.83	33	-
Electric toilet seat	115	210	0.55	28	***

Note 1: UEC is unit electricity consumption. Note 2: Refrigerator and electric toilet seat are temperature adjusted UEC, and TV is usage adjusted UEC. Note 3: Except for rice cookers, all appliances have actual UEC that are significantly different from the Labeled UEC at the 0.01 significance level. For rice cookers, the difference is not statistically significant even at the 0.1 level.

Conclusion

In Japan, in addition to their relevance as climate change countermeasures, electricity saving measures have become an urgent topic in their own right, but existing data were insufficient to understand the structure of electricity demand of household appliances. With the objective to understand in detail the breakdown of household contributions to CO_2 emissions, the Ministry of Environment carried out a questionnaire survey and an end-use metering survey.

In this paper the composition of household electricity use has been presented, from results of an end-use metering survey (over about a 7-month period) and a questionnaire survey about lighting equipment and usage, conducted in 56 households in the Tokyo metropolitan area and in Hokkaido (a cold climate region). Over the measurement period, on average, it was possible to account for 79% of total household electricity use in the Tokyo metropolitan area and 87% in Hokkaido, including estimated values for lighting.

Additionally, the composition of electricity consumption during grid peak demand hours was also shown. During the Tokyo metropolitan area's summer grid peak hours, electricity consumption in the metered households could be broken down into AC with 38%, refrigerators with 25%, and TV sets with 7% of total household consumption. In other words, these three appliances accounted for a 70% share. The winter peak hours in the cold climate region of Hokkaido occur in the early evening, and various appliances contribute to household electricity consumption. However, it is noted that on very cold days in Hokkaido, electricity demand in the late night and the morning is also very high.

For appliances with energy efficiency standards that specify annual electricity consumption as an energy efficiency indicator, the metered results were compared with the labeled values. For refrigerators and freezers, the actual UEC was 1.6 times the labeled value. However, for units made in or after 2006, when the standard measurement conditions were revised, this difference was smaller, and both the UEC and the UEC per rated volume tended to decrease. TV sets and DVD recorders also exceeded their labeled UEC, probably due to being used in a different mode than that specified in the standard measurement conditions. Microwave ovens, rice cookers, and electric toilet seats used less than their labeled UEC, but the difference was not statistically significant for rice cookers.

Acknowledgements

We are grateful to the Ministry of the Environment, Government of Japan, for sponsoring our work for the report "Structural analysis and encouragement of model business subcontractors for electricity conservation and CO2 reduction" (*setsuden CO2 sakugen no tame no kouzou bunseki jissen sokushin moderu jigyou suishin itaku gyoumu*) in 2012. We appreciate Barbara Litt's help in translating this paper from Japanese.

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Development of an interactive web application to improve residential end-use efficiency

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Abstract

In South Africa and elsewhere, electricity supply exigencies and a need to promote the sustainable use of resources have prompted an emphasis on affordable, rapidly scalable solutions in the form of Demand Side Management and Energy Efficiency. The improvement of end-use energy efficiency is generally accepted as an obvious, simple and inexpensive measure to manage a consumer's energy demand. Residential electrical end-use has been identified as an area where the potential for change exists and the research documented in this paper is aimed at a residential end-user. The ability of an interventionist strategy to harness this potential determines its effectiveness in delivering desired results. The paper describes the development of an interactive web application for residential end-users as an intuitive, dynamic tool to improve energy efficiency through modified consumption behaviour and the adoption of energy efficient habits. Emphasis has been placed on the education of end-users through exposure to energy efficient guidelines and consumption analysis. Current web technology was evaluated and the resulting format is a Rich Internet Application favouring an interactive, minimalistic design with graphic content. "At-a-glance" feedback is presented by means of data visualization to resemble a dashboard. With extendibility and ease of maintenance in mind, the desired functionality and dynamic content have been achieved through a relational database-driven design structured around electric end-use categories and associated household appliance types.

Introduction

The vulnerability of energy systems impacts energy security on economic, technical and social levels. At a micro-economic level, this vulnerability determines how exposed consumers are to possible interruption of supply as well as an increase in price [1]. In 2008, supply-related issues culminated in a large-scale power crisis in South Africa. Insufficient coal supplies, infrastructure requirements and supply disruption had depleted the country's electricity reserves and caused immense pressure on the state-owned electrical supply utility, Eskom. The course of events underlined the pressing need for affordable, rapidly scalable solutions in the form of Demand Side Management (DSM)/Energy Efficiency (EE) initiatives to reduce disruptive measures such as load shedding [2].

Eskom's ability to deliver sustained energy security is routinely beleaguered with bureaucratic issues and concerns. South African consumers must adjust to a steep electricity price increase to compensate for a lack in investment in generation capacity and a historically too low electricity price. In the beginning of 2010, the National Energy Regulator of South Africa (NERSA) approved the implementation of a sliding-scale tariff-based structure for the residential customer base in the form of an Inclining Block Tariff (IBT). A Time Of Use (TOU) pricing scheme correlates electricity price with time of consumption and according to the tariff structure, higher consumption customers will be charged more based on their electricity usage. The time-based pricing scheme for the suburban residential sector with relatively high consumption, will be phased in once advanced smart metering infrastructure is in place. The IBT roll-out by Eskom commenced in the first half of 2010 [3].

The category of households whose fuel expenditure is in excess of 10% of the household income is deemed vulnerable to fuel poverty [1]. However, as electricity consumers are demanding higher levels of reliability, efficiency and environmental performance [4], coupled with the need to promote the sustainable use of resources, the introduction of simple interventionist measures to manage consumer energy demand can significantly benefit most households. This research paper documents a number of key aspects of the development of a tool to educate residential end-users on energy efficiency and improve end-use energy efficiency by means of an interactive, web-based application. The provision of consumption analysis feedback in the form of appliance usage profiles, can assist a consumer in realizing the cost benefits associated with appliance scheduling based on a TOU framework.

Energy Efficiency (EE) and Demand-Side Management (DSM)

The cumulative residential load on a power system or part thereof, is determined according to different residential customer types whose household activities are unique yet in accordance with certain predictable usage patterns. In order to establish energy security within the energy provision-consumption context, DSM involves all interventions that occur on the demand side (as opposed to the supply side) where the end-user resides. Consumer participation within the residential sector can minimize peak hour consumption through the implementation of measures such as appliance scheduling and a more judicious use of electricity. Demand in most households can be directly correlated with family activity peak times and is simultaneously linked to affordability, lifestyle and preferences [5]. Knowledge of household consumer loads is considered essential in order to both forecast demand at utility level and to predict potential savings through DSM schemes. In recent years, an extensive body of research knowledge has been collected on interaction between members of a household and their appliances and how consumption is defined by non-technological factors such as price, convenience and habit.

End-use analysis is proposed to be the best way to study load usage in order to fully grasp and model customer usage and is defined as the study of basic causes of electric demand by customer type, time, end-use category, and type of appliance [5]. Disaggregation of residential consumption has been applied in research studies as a means of distinguishing between different energy consuming appliances to reveal consumption trends. As noted by Paatero and Lund, unless exposed, "(t)he fluctuation of electricity consumption concerning an individual household remains unrevealed as well as the division of consumption between different types of household appliances." [6]

Findings from a study on the effectiveness of feedback on energy consumption indicate that, domestic energy use is largely invisible to the user and most consumers are ignorant of their consumption behaviour, i.e. how much energy they use towards various ends [7]. Consequently, consumers are also ignorant of the effect of modified behaviour through an investment in efficiency measures. The case for feedback is put forward as a measure to "make energy more visible and more amenable to understanding and control" [7]. The author recommends a user-friendly display to show "instantaneous usage, expenditure and historic feedback as a minimum, with the potential for displaying information on microgeneration, tariffs and carbon emissions" for optimal usefulness [7].

Overview of end-user feedback

The research documented in this paper underwrites the proposition that, through readily accessible real-time feedback, consumers can adjust usage patterns in accordance with energy efficiency principles. The utilisation of instantaneous direct feedback can serve as means to devolve and transfer both control and ownership to the end-user. Feedback should enable the consumer to immediately see the effect of switching on an appliance and realise the benefits of a reduction in consumption.

Feedback is associated with a learning process through its contribution to the end-user's implicit knowledge repository. Through the exercise of interpreting feedback on energy supply and usage, end-users assimilate information concerning their energy use which in turn prompts them to act and modify their behaviour in some way [7]. The combination of a home energy audit and "disaggregated" feedback, made available as at-a-glance displays, can reveal to the end-user which end-uses consume most energy. The rationale for this type of feedback is based on the educational value in raising awareness of the relative demand from different appliances. Disaggregated feedback can be included in billing in a format such as a pie-chart to display a typical breakdown of main domestic end-uses [7].

The feedback system in this research is conceptualized as a virtual residence which the end-user can construct and populate with appliances to observe the effects of various end-use scenarios. A web application was used to accomplish this and channel feedback to the user by means of a dashboard interface. A dashboard is nowadays commonly associated with a real-time user interface to convey an organization's Key Performance Indicators (KPIs).

Efforts in recent years have been made to develop residential energy management systems to intelligently manage and raise awareness about residential energy consumption [8]. This has given rise to the development of both commercial projects such as Microsoft's System Hohm, and freely available energy monitoring tools such as Google's PowerMeter [9]. Nevertheless, the GoogleMeter service was retired in September 2011 and similarly Microsoft's Hohm has been halted [9]. A number of conjectures are put forward as to why the big Internet companies' online energy monitoring tools have failed [10]. One reason considers the American market for home energy management to be still too immature and that the online energy tools were prematurely introduced.

In comparison with the American market, there is a far greater financial incentive for South Africans to utilise energy saving tools. When measured in real terms, the cost of residential electricity in the US decreased by an annual average of 0.8 percent in both 2012 and 2013 [11]. In terms of disposable income, an average American household spends far less on electricity compared to a South African household.

To date there is no market research available from the Human Sciences Research Council (HSRC) in South Africa on how the South African market may respond to online energy metering tools. In February 2012, the European Utilities Telecom Council (EUTC) and Eskom held a conference on the Smart Grid in Africa in view of planning for the development and deployment of smart metering [12]. Eskom's spokesperson noted that the commercial viability of smart metering still needs to be demonstrated since it is key to be able to deploy and interface with existing systems [13].

South Africa's diverse demographic make-up poses a challenge in identifying the target market and the average end-user with whom to engage during the design process. An honest review is required of what can be most effectively accomplished, yet presented and communicated in a simple, intuitive way. Although income levels are indicative of end-user energy consumption, a high earning household does not necessarily waste energy. Similarly, an indigent household does not necessarily consume energy prudently. Despite the marked differences in literacy levels amongst South Africans, the technological dexterity of the youth, forming a large portion of the South African society, and the ubiquitous presence of smart phones set the stage for a high adoption rate of a web-based application. With many metropolitan schools in South Africa providing computers with Internet access and with increased access to wireless (Wi-Fi) network points, the channels to modify energy consumption behaviour and cultivate awareness of EE habits are more readily available.

Profiling residential electrical energy demand

Domestic demand can be qualified by means of end-use energy models by considering particular end-uses. The accuracy of end-use models is dependent on grass-root level consumption details such as appliance inventories and associated usage profiles [6]. Demand is determined as a load-average for a given time period referred to as the "demand interval", for example measured for 15 minute intervals, 30 minute intervals, or on an hourly, daily, monthly or annual basis [5]. Demand which is measured and recorded on an hourly or half-hourly basis for one day yields a load curve. If measured half-hourly, there are 48 intervals and each of the values is an indication of the average demand for that interval. The domestic load profile fluctuates on an hourly, daily and seasonal basis [5]. Demand for lighting, for example, is characterized by a daily pattern, varying according to the time of day, i.e. usually highest in the early morning and after dusk. End-uses such as cooling and heating exhibit seasonal variations as accompanying weather conditions impact daylight hours and ambient temperatures.

An energy profile associated with an appliance depicts its usage over a designated period of time, such as a half-hourly energy consumption profile. For DSM interventions and EE initiatives, conventions that apply in the field of Measurement and Verification (M&V) are used to consolidate consumption into half-hour intervals associated with applicable TOU tariffs [15]. Indicators such as Half-hourly Energy Consumption profiles and Cumulative Energy Consumption are typically included in feedback information. Cumulative Energy Consumption, as the sum of the half-hourly energy consumption profile values for a specified period, is reported as kW demand.

Instead of directly measuring demand, daily half-hourly energy consumption profiles can be calculated from knowledge of the appliance's kilowatt (kW) rated value and a user-defined period. Based on the user's choice of appliance, a database query can extract the appropriate kW value and, together with the user's input of start- and end-timestamps, the appliance's energy consumption can be calculated. Proceeding in this way, a daily energy consumption profile over 48 half-hour intervals 00:00, 00:30, 01:00 etc., can be constructed for one or more appliances.

It is conventional to utilize one of two time-stamping formats in M&V, namely forward filling and backward filling timestamps [15]. In the case of forward filling timestamps the associated energy consumption value designates the value for the half-hour starting at the time-stamp value. In the case of backward filling timestamps the associated energy consumption value designates the value for the half-hour ending at the timestamp value [15]. Forward-filling timestamps are used in the application.

Appliance duty cycles

Unlike resistive loads such as lights, toasters and kettles, a number of appliances' operation exhibit cyclic on and off temporal patterns. These cycles are referred to as duty cycles and are features of appliances that typically have an embedded controller such as a temperature control system. Appliances that have duty cycles are for example hot water geysers, air conditioning units, heaters, refrigerators and freezers as well as dishwashers and washing machines. Most of these appliances have, as part of their control system, a thermostat to control temperature. For example, in the case of an air conditioning unit, during the hottest part of the day the unit will remain on for longer and off for shorter periods in order to achieve and maintain a required set ambient temperature [5].

It is important to differentiate between an appliance duty cycle, which is intrinsically part of the operation of some appliances, and a user-initiated usage cycle, as illustrated in Figure 1. When a user switches on an appliance such as a washing machine at 06:15 on a weekday morning in summer, the user has initiated a usage cycle. If that is the usual time that the user uses the appliance on a weekday in summer, a usage pattern or profile can be identified for the particular appliance. On the other hand, once the washing machine is switched on, and depending on its setting, the appliance itself runs through an appliance specific pattern of on and off cycles of variable duration. These duty cycles will vary based on the particular machine's washing, rinsing or spinning cycles.

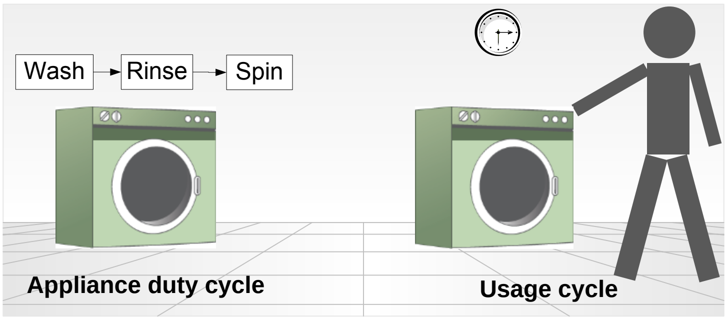

Figure 1: Appliance duty cycle versus usage cycle

To avoid compromising accuracy, the software application makes provision for controlled appliances through the inclusion of duty cycle data in the background as shown in the diagram in Figure 2. Duty cycle data was obtained and stored in a database during a case study in which household appliances were logged to generate event log data.

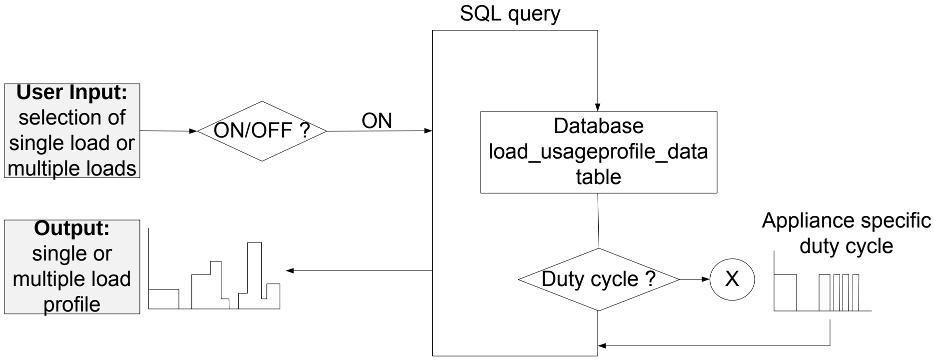

Figure 2: Incorporation of duty cycle data in profiling consumption

Since appliances, such as washing machines and their settings, vary greatly, it is not feasible to establish a universal duty cycle pattern per appliance. Extensive research would be required in order to accumulate such data for all household appliances whose operation display cyclic on and off patterns. However, for a more accurate representation, duty cycle data should be incorporated during the creation of usage profiles of relevant appliances/loads.

Application Development Methodology

Design

The research was aimed at creating a tool to educate an end-user on the benefits of improved energy efficiency through changed attitudes and behaviour. The design philosophy has therefore been focused on the need to extend both information and control to the user by means of a real-time feedback system. System inputs are tailored around the user's specific end-use scenarios with associated load types and energy-consuming activities.

A dynamic application ensures extendibility and ease of maintenance. To achieve a dynamic application, the design is divided into a server side, to provide dynamic content by means of a relational database, and an interactive user interface on the client side, as demonstrated in Figure 3.

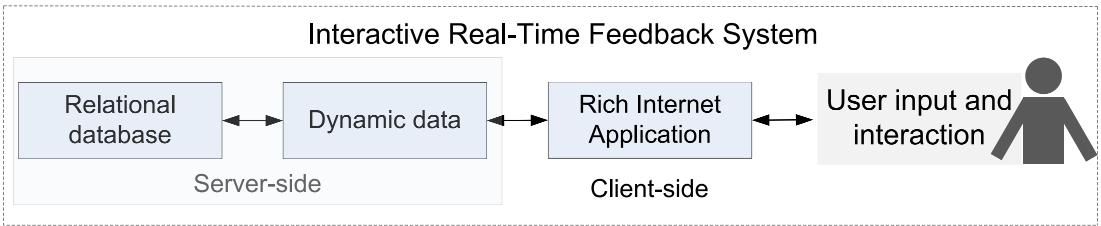

Figure 3: Interaction between the client and server sides

The relational database is structured around end-use categories and appliance types. The database is a data repository associating certain end-uses with certain areas or venues. Accordingly, only those appliances which are grouped within certain end-use categories would be available choices for the user. This logical grouping constrains the number of scenarios which a user can create, as illustrated by the intersection shown in the Venn diagram in Figure 4.

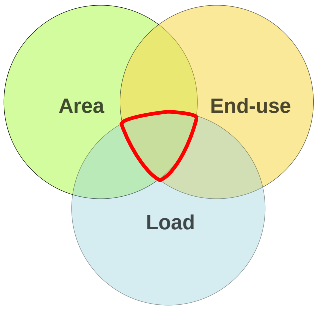

Figure 4: Intersection between area, end-use category and load type

Under normal circumstances, a user will not have a washing machine in a dining room or a microwave in a bathroom. The application caters for the general case, whereby an activity is associated with the most likely venue choice. An end-use category such as laundry is therefore associated with areas such as a kitchen, scullery, garage or bathroom.

Two platforms were used during the development and testing of the application, namely Microsoft Windows and the UNIX/Linux platform with their respective open-source stacks, i.e. WAMP (Windows, Apache, MySQL and PHP) and LAMP (Linux, Apache, MySQL and PHP).

Extensive research was conducted to collect data on common household appliances and their electrical power ratings for inclusion in the MySQL database. For the client side, current web technology was evaluated and the resulting format is a Rich Internet Application (RIA) favouring an interactive, minimalistic design with graphic content. An RIA provides more seamless data exchange and interactive features resulting in a richer user experience than traditional page-based HyperText Markup Language (HTML) applications. The following considerations were taken into account:

- Ease and speed with which to achieve a complex level of interactivity.
- Cross-browser compatibility.
- Full integration with a MySQL database where Hypertext Preprocessor (PHP) can be used as the scripting language to facilitate the data exchange between the client and the server side.

At the time of the application’s development, Flash technology, using the Flex framework, was best suited to achieve the desired functionality, although HTML5 is now making similar features more available. A Flash Player plug-in (downloadable for free) is required, however, the adoption rate is high and if a user’s computer does not have a current enough version, a prompt to upgrade will follow. With regard to future deployment alternatives, Flash content is, however, not supported on all mobile devices. To date, Apple is famously resistant meaning that iPhone and iPad users cannot view Flash content.

Emphasis was placed on designing for the user, otherwise referred to as "User Experience Design", which relies on the implementation of three primary aspects, i.e. Content Strategy, Interaction Design and Visual Design [16]. A number of principles for effective user interface design was originally developed by Molich and Nielsen [17] and since distilled by Nielsen to a set of "Usability Heuristics" [18]. The following four have been considered most significant during the application’s development:

- *Conformation between the system and the real world:* The system design should adopt familiar conventions with which the user can relate. The presentation and ordering of information should appear natural and logical. The design and terminology should be user-oriented as opposed to system-oriented.
- *Consistency and standards:* Ambiguity should be avoided so that users do not have to wonder about the meanings of different words, situations or actions.
- *Enhanced visibility:* Visibility should be promoted in favour of reliance on the user's ability to recall objects, actions and selections. Dialogue and program flow should demonstrate a sense of continuity. Instructions for system-use should be easily perceptible and retrievable as needed.
- *Clear and minimalist design:* Essential and relevant information must be conveyed, since a focus on one particular area or dialogue inadvertently reduces the relative visibility of other areas.

Usability engineer, Donald Norman, cautions against the tendency to increase complexity through the addition of features which in turn leads to a decrease in usability and comprehension [19]. According to Wood and Newborough, a design should establish preferred or optimal display arrangements by restricting features which are not absolutely necessary and organizing and grouping features to broadcast a message of simplicity [20].

Implementation

Interactive features such as drag-and-drop functionality as well as data visualization were implemented to create the concept of a virtual residence that is designed to combine simplicity with a user-friendly, intuitive approach. The development of the application and its Graphical User Interface (GUI) was accomplished by implementing the four usability features within the framework of Content Strategy, Interaction Design and Visual Design as follows:

- Content Strategy:
  - Logical layout and navigation.
  - Graphic content in the form of generic icons.
  - Dashboard presentation with panels and charts.
  - Dropdown boxes with filtered choices based on dynamic database-driven content to reduce typed data input and dialogue.
  - Preserved data integrity and avoidance of SQL injections by keeping user input to the minimum.
- Interaction Design:
  - Rich Internet Application technology with event-driven features such as click events and interactive charts.
  - Drag-and-drop functionality.
  - Dynamic client-server data exchange.
  - Intuitive navigation.
- Visual Design:
  - Use of graphic icons to minimize text and dialogue.
  - Watermarked areas to support recognition rather than recall.
  - Dashboard "at-a-glance" presentation.
  - Data visualization using Flex native charts and 3rd party charting solutions.

The application combines the above design features with the following functionality in a three-tier arrangement whereby the user can perform certain tasks:

- Survey:
  - Create a virtual residence.
  - Conduct an appliance audit in order to identify electrical loads within the residence.
- Analysis:
  - Analyse installed capacity based on different end-use categories.
  - Analyse appliance usage through division of consumption.
  - Select an appliance and assign a daily usage profile to it by determining the times during the day when the appliance is in use. The user can thereby characterize and create a load profile based on appliance-specific usage.
  - View a resultant daily usage profile generated from the accumulated usage profiles of a number of appliances.
  - View a cost analysis by combining the time of appliance operation depicted in the usage profile with a Time Of Use (TOU) tariff structure.
- Educational guidelines:
  - Raise awareness and educate the user through exposure to practical energy efficient guidelines.
  - Educate the user on the load characteristics of common household appliances.

This functionality is summarised in Figure 5:

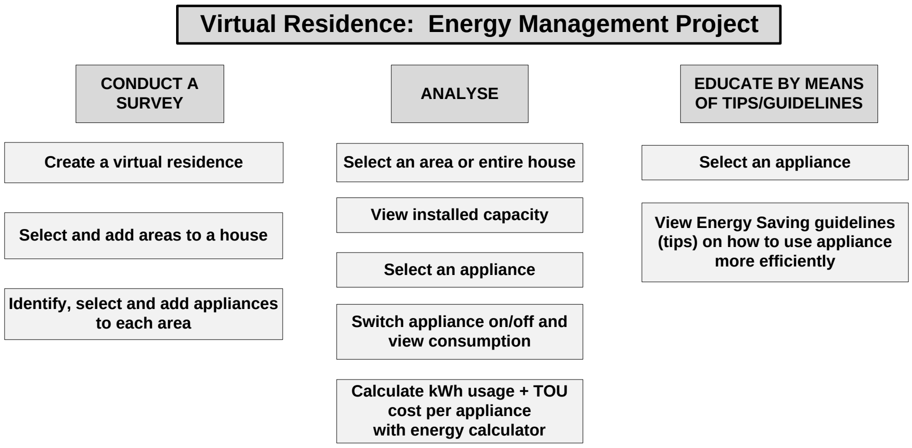

Figure 5: Three-tier functionality of the web application

Figure 6 and Figure 7 present some features of the GUI. Implementation of the concept of "recognition rather than recall" was accomplished by means of a watermarked area within the virtual residence, as illustrated in Figure 6:

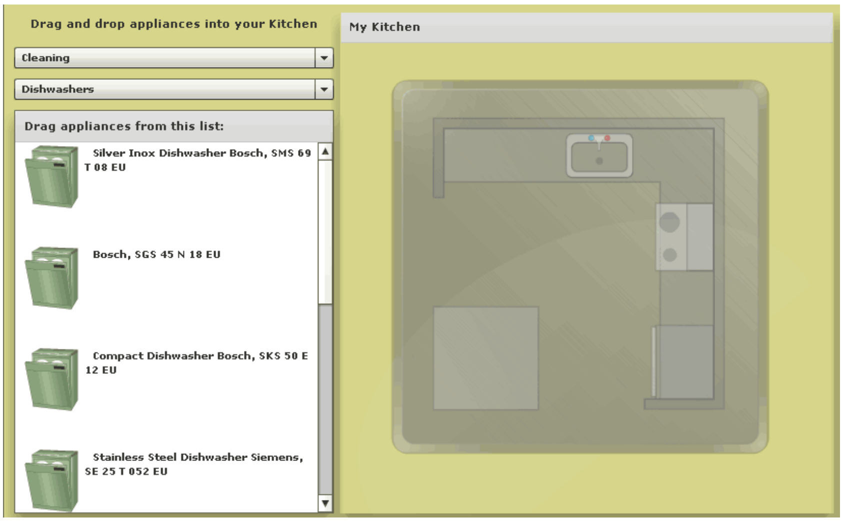

Figure 6: Virtual residence with watermarked area

Figure 7 provides an example of logical grouping for simplicity and disaggregated guided feedback from which the end-user can view installed capacity for a specific virtual venue and for a specific end-use category.

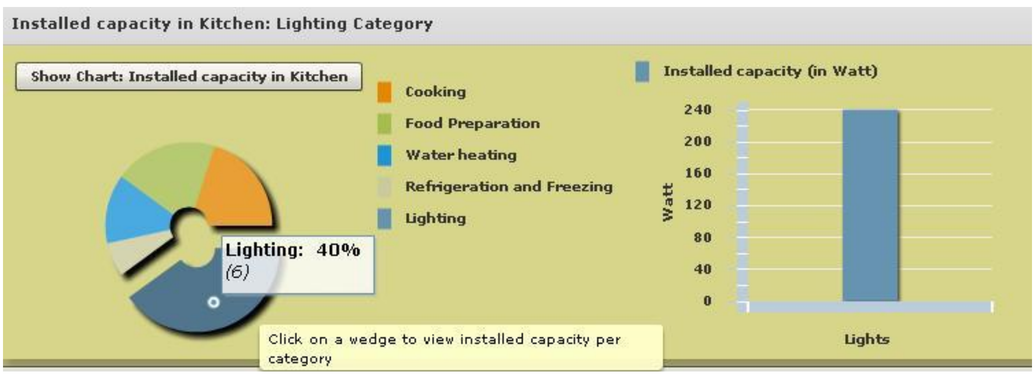

Figure 7: Disaggregated feedback showing installed capacity per venue and per end-use category

User-defined daily usage profiles

Various types of feedback of varying complexity and detail can be utilised by means of data visualisation objects such as charts. The following end-user feedback regarding appliance usage is incorporated in the application:

- ON/OFF daily profile for a specific appliance or load.
- Daily average ON time (as %) per half-hour interval for a specific appliance or load.
- Cumulative daily kW demand for a user-defined selection of appliances.
- Comparative/relative daily kW demand for a user-defined range of appliances over a defined period.
- A daily TOU cost profile per appliance.

The conceptualization of a user-defined ON/OFF profile is shown in Figure 8, whereby a user can define a specific usage pattern per appliance:

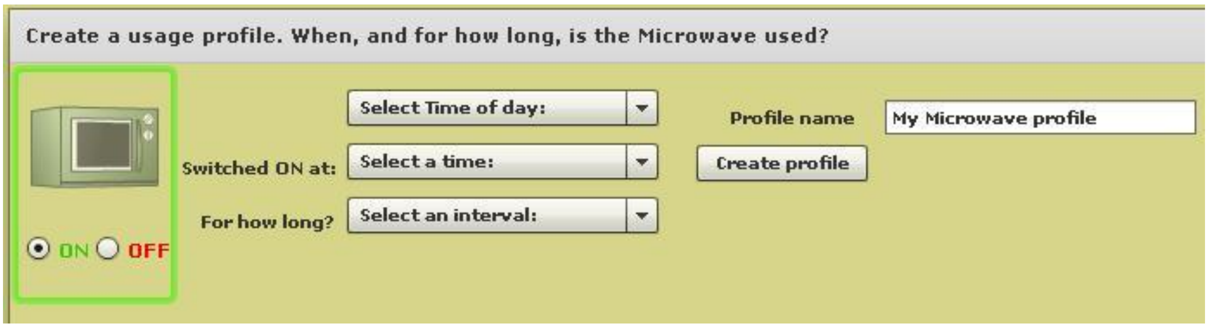

Figure 8: Conceptualization of a user-defined ON/OFF profile

An example of an ON/OFF profile for an individual load is shown in Figure 9 where the ON/OFF cycle is portrayed by switching between 1 and 0. Depending on the choice of appliance/load by the user, duty cycle information would automatically be incorporated into a profile.

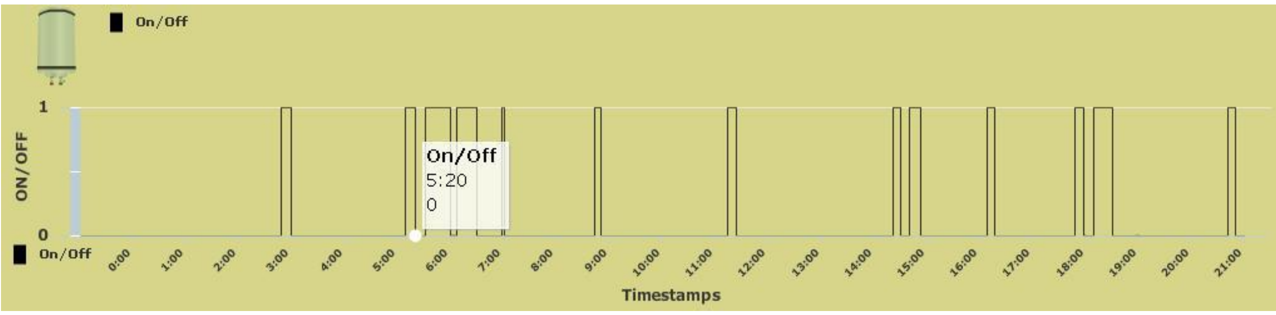

Figure 9: User-defined ON/OFF profile for a geyser with duty cycle information incorporated

As shown in Figure 10, the user can be provided with feedback on the average daily ON time (as a percentage) for one or more user-selected appliances.

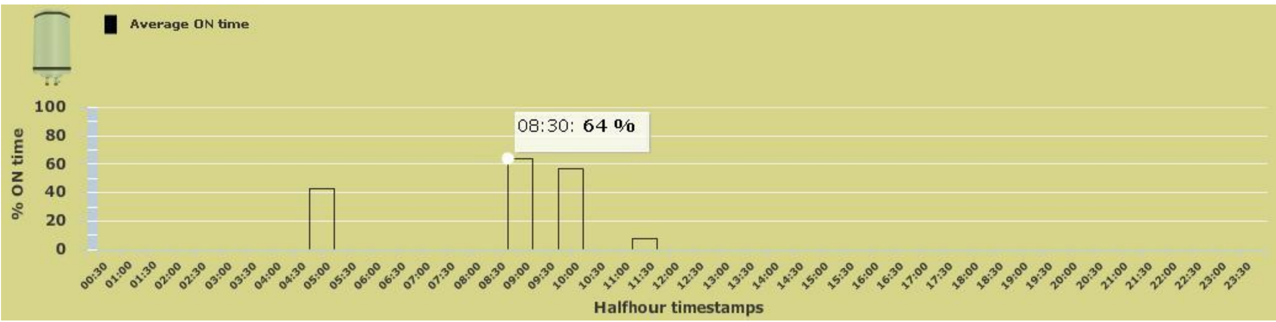

Figure 10: Daily average ON time (%) per half-hourly intervals for a geyser

Figure 11 shows feedback in the form of cumulative kW demand for one day for a selection of loads:

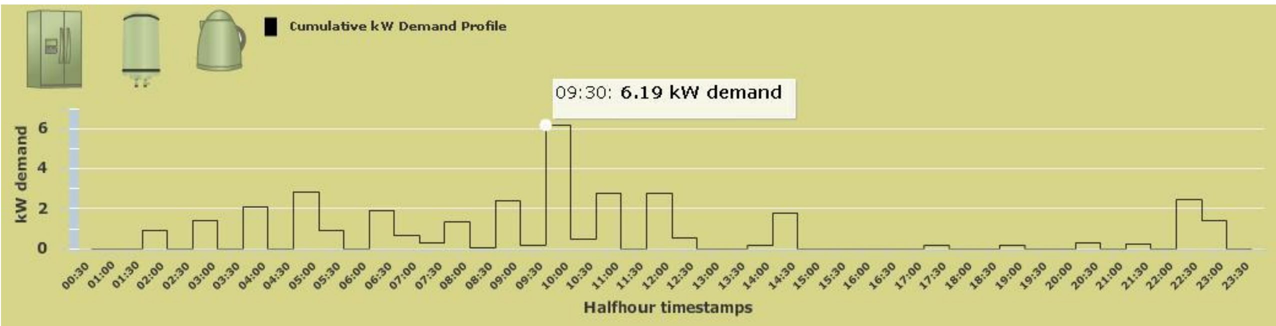

Figure 11: Cumulative daily kW demand for three user-selected appliances

Figure 12 portrays feedback in the form of a grouping for three consecutive days so that the user can compare relative demand for a user-defined set of appliances/loads.

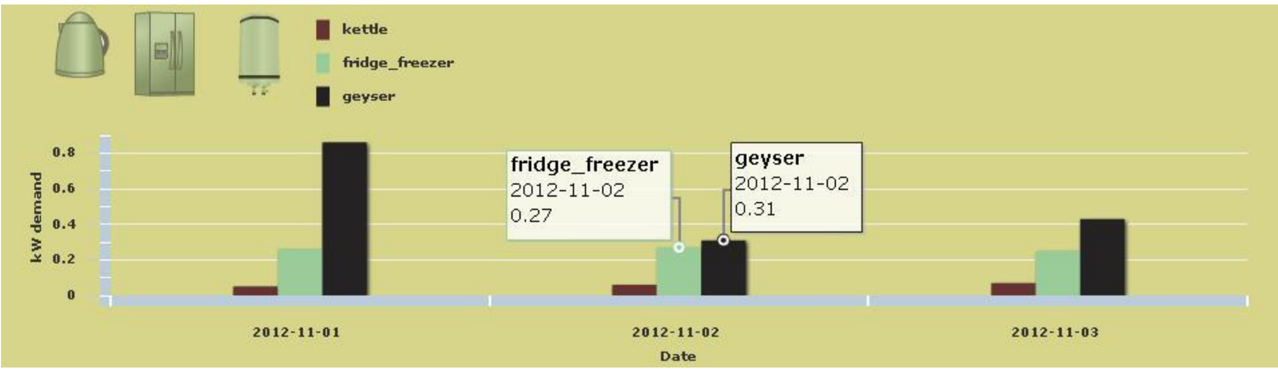

Figure 12: Three-day comparative kW demand for a user-defined set of appliances

The TOU pricing scheme applicable for suburban South African residential consumers will be phased in once advanced metering infrastructure is in place [3]. Based on the TOU pricing scheme, the following functionality, shown in Figure 13, is included in the application tool to provide user feedback in the form of a cost analysis and encourage appliance scheduling.

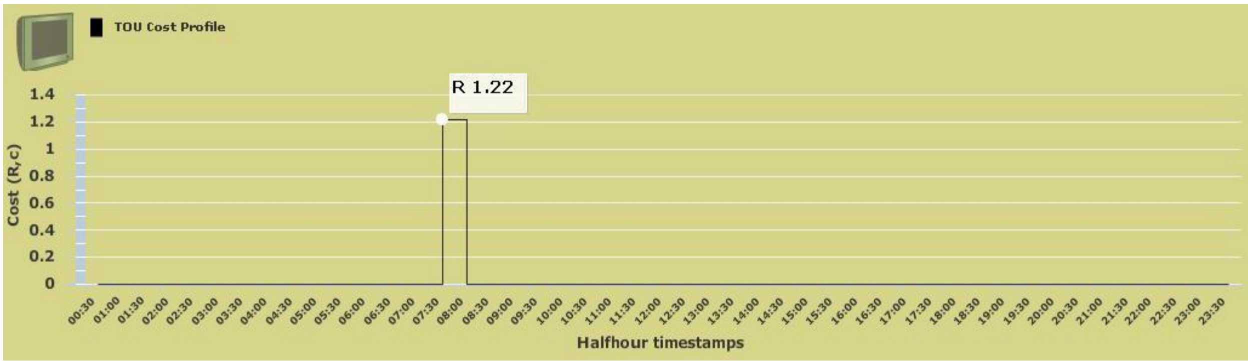

Figure 13: User-defined TV usage and TOU cost profile for one day

Test case

The web application was applied to a middle-income residence within the Stellenbosch municipal area in the Western Cape. The household consists of four members, namely two adults and two children. A virtual residence was created followed by an appliance audit per area/venue in order to establish both an area inventory and a loads inventory. The analysis features were tested and usage profiles were generated for a number of the appliances. As recommended in the next section, assessment on two different levels is required, i.e. testing of the technical features and market research.

Conclusion and recommendations

Active participation by consumers to improve EE requires some form of intervention to educate and raise awareness. The paper has promoted the use of a feedback system as a tool to transfer knowledge and control to the end-user to reduce energy consumption and improve efficiency. The research outcomes have been the product of an investigation into various technology and display options in order to ensure the presentation of fairly complex functionality in the simplest, most intuitive fashion. The resultant feedback interface has been a web application in the form of an RIA to present the end-user with relevant information. Dynamic interactivity has been achieved through the development of a relational database on the server-side.

Recommendations

Further development and ongoing research would be required in terms of the database to ensure up-to-date, comprehensive content with regards to common household appliances.

It is proposed that the application's technical features are reviewed by releasing a beta version of the application to a selected focus group. Based on the outcome, an iterative software development process will follow to prepare a version for the next phase of testing.

A test group, representative of the South African population, would need to be identified to use the application as part of a survey in order to evaluate aspects such as:

- How is the application received by a varied group of end-users?
- Is the application's design and layout user-friendly and intuitive?
- How effective are the educational guidelines and real-time feedback for end-users to make sensible consumption decisions?
- Can the application meet the overall objective of encouraging consumers to reduce consumption and adjust their usage patterns by, for example, scheduling appliances?

Evaluation of adjusted consumption patterns can be accomplished by comparing the test group to a control group who have had no exposure to the application.

Based on the outcomes of the evaluation stages, it may be worthwhile to investigate the creation of a mobile application or "app" in order to migrate to a mobile platform in addition to the web platform. Incorporating the application with technology employed in smart metering could also become a consideration in order to interface with smart systems.

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The impact of home energy feedback displays and load management devices in a low energy housing development

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Abstract

Home energy feedback display and monitoring systems are a key feature of Australia's leading eco-friendly housing development at Lochiel Park in South Australia. The displays comprehensively measure electricity, gas and water usage in real-time, and can manage loads during periods of peak electricity demand. The houses are designed to be near net zero energy homes and incorporate a high performance building envelope, roof-mounted photovoltaic panels, solar water heaters and energy efficient appliances.

The paper describes the display and monitoring systems, summarises samples of delivered energy results for selected households, and the average for Lochiel Park. The results show that despite living in similarly constructed houses, often with the same number of occupants, there are significant monthly and annual variations in net delivered energy.

In addition, this paper draws on a series of in-depth interviews to discuss the residents' attitudes towards, and experiences interacting with, the in-home feedback display and associated energy systems, and describes how feedback displays may assist residents understand their end-use energy behaviour, reduce their net energy use, and assess whether household appliances and energy systems are operating correctly.

The interview responses reveal a mostly positive attitude to the energy feedback displays, but a generally negative attitude towards the load management system. This negative response may be due to the lack of perceived benefits from such a device, and a poor understanding of how to operate this feature. Finally, this paper outlines the residents' suggestions for improving the energy feedback monitoring systems.

Background

Evidence presented by world leading climate scientists is showing that anthropogenic greenhouse gas emissions has reached the level which is altering the global climate, and continued high use of carbon based fuels will further exacerbate the problem [1, 2]. Leading economists have suggested that human impact on the global climate is one of the greatest economic, social, political and environmental challenges facing this generation and our immediate future generations [3, 4].

In most developed nations housing has evolved to the degree that households expect high levels of thermal comfort, the convenience of an almost endless supply of electricity available at the flick of a switch, and hot water on demand, irrespective of the environmental impact of making that energy available [5]. Increasing demand for thermal comfort and other energy services around the world, combined with factors such as increasing population, all contribute to a continuing upward trend in energy demand [6]. Housing expectations and cultural norms, embedded institutional construction practices, regulatory standards and dominant technologies have evolved without due consideration of the resultant ecological footprint [7]. What we build, the appliances we install, and the way we operate our buildings is the result of many social, economic and technical influences, such as the cultural institutions that shape communities, the technology norms applied by industry, the education and training of actors that meet market demand for new housing, and the experience of households that demand and use new residential products [8]. This interaction of actors, institutions, rules and technologies over many years has brought us to the point where housing in many nations has a significant negative impact on the local environment and the global climate [9].

Concern for anthropogenic greenhouse gas emissions has prompted individuals, communities and governments in many countries to consider reducing building energy use and thus lowering the carbon impact of the building sector [6, 10]. Researchers and government agencies alike have suggested that improving the energy and carbon performance of residential buildings will play a key role in delivering substantial and sustainable greenhouse gas emission reductions in developed economies [11-14]. This energy and carbon emission reduction will likely be the result of changes in the technology applied to buildings, changes to the design of buildings, and changes to the way we operate our buildings and appliances [15].

Responding to concern over building energy use and residential greenhouse gas emissions, the South Australian Government chose to showcase the cutting edge of climate relevant sustainable urban development by creating Lochiel Park, a model green village of national and international significance [16].

Creation of Lochiel Park

The Lochiel Park Green Village is a planned estate of 106 residential dwellings, created though the policy initiative of the State Government of South Australia, with estate design and management by a government agency, infrastructure and housing constructed by the private sector, and the majority of dwellings sold to the general public through the local real estate industry.

Located on 15 hectares of surplus government land, approximately eight kilometres North-East of the Adelaide central business district [17], the development was originally intended to be disposed to the property market as a standard broad-acre land sale of 150 residential allotments, but a change of state government introduced new policy objectives including an increased interest in environmental outcomes [18]. This resulted in the Premier of South Australia declaring in 2004 of the project's new intent [18]:

> "I want South Australia to become a world leader in a new green approach to the way we all live. The Lochiel Park Development will become the nation's model 'Green Village' incorporating Ecologically Sustainable Development (ESD) technologies."

Given explicit direction from the State Premier to develop a niche green urban estate of world standing, an advisory panel of state and local government officials and community representatives was established to define high level objectives across a relatively broad range of areas including environmental sustainability, social sustainability, urban form, transport, industry development and economics [17]. By benchmarking against major international and national niche green residential developments, performance targets were set covering potable water, open space, water recycling, energy technologies, revegetation, solar passive design, waste reduction and management, designed building life span, local transport use, community interaction, and many other impacts. These detailed targets were refined in consultation with the various expert groups [18], with final design overarching targets set at a reduction of:

- 66% energy used
- 74% greenhouse gas emissions
- 78% potable water use

Expert consultative groups for energy and water were used to translate the original targets into rules and guidance materials that could communicate the desired sustainability principles to be applied to each house. These were published in the Urban Design Guidelines [19], with minimum requirements including:

- 7.5 NatHERS Stars thermal comfort[1]
- Solar water heating, gas boosted
- 1.0kWp photovoltaic system for each 100m^2 of habitable floor area
- High star rated (highly efficient) household appliances
- Low energy lighting (CFLs & LEDs)
- Ceiling fans in all bedrooms and living spaces (to promote air movement)
- Rainwater harvesting feeding the hot water system
- Treated storm water feeding toilets, cold laundry taps and irrigation
- An in-home energy use feedback display (in a location that encourages resident interaction)

The Guidelines established a new set of rules, calling for practices outside existing institutional and professional norms, requiring the application of technologies and systems uncommon to the mainstream building industry, and the consideration of new performance indicators bringing new concepts to building design and construction practices. These Guidelines meant that households were exposed to different technologies and styles of house design compared to new dwellings commonly available in South Australia.

Upon the release of the Guidelines, housing product was offered to the open market in 2007 with construction of the first homes beginning in 2008. The majority of the housing allotments had been sold by mid 2011, and the majority of the homes completed and occupied by late 2012.

[1] The star rating indicates the dwelling's predicted annual heating and cooling requirement to maintain human thermal comfort, which is determined by a computer program that considers the dwelling's fabric and form, and assumed user behavioural patterns for a nominated climate year (see www.nathers.gov.au). A star rating of 10 means that that no external heating or cooling is required, whilst a star rating of 0 means that the building shell does practically nothing to reduce the discomfort of hot or cold weather.

This paper provides an insight into the energy performance of this green village, and in particular examines the effectiveness of in-home energy feedback displays in encouraging behaviour change. The paper is structured to provide a short review of the academic literature on the use and effectiveness of energy feedback displays, discuss the methodology and monitoring systems used in Lochiel Park, explore the energy performance of the development, and examine the findings from the in-depth household interviews.

Literature Review

Energy use feedback typically exists in the form of periodic energy bills or through the need to gather and prepare fuel for cooking, heating and cooling or lighting. In developed and many developing countries, energy use feedback is often provided by regular bills based on metered consumption or predicted consumption of electricity, gas or liquid fuels. This feedback process is temporally removed from the day to day energy services that are responsible for the energy use, with billing intervals often monthly, bimonthly or quarterly. Metered bills typically show cumulative consumption over the billing period and are very unlikely to disaggregate consumption by end-use or time, while bills based on estimated consumption prevent households from recognising any relationship between energy services and energy use [20]. More recently, complex real-time of use information, even disaggregated to typical end-use, has become possible via computers, mobile phones, and other portable devices [21].

Readily accessible energy use information for households has been found to facilitate experimentation, encourage learning and support good energy management practices, but while feedback is necessary for the learning process, feedback on its own may not be sufficient to bring about behaviour change [20, 22]. Darby [20] notes that energy use feedback has an educational impact as well as directly impacting behaviour, facilitating a greater consumer understanding of the relationship between energy services and energy use.

Energy feedback is not limited to the provision of energy use information. The recent acceleration in the uptake of domestic rooftop solar photovoltaic panels by the general public has meant a more widespread distribution of electricity generation and household tracking of energy generation data. Evidence is available demonstrating that building-integrated electricity generation with feedback displays can lead to energy demand reduction [23, 24].

A number of studies have identified energy savings associated with the use of in-house energy feedback displays [20, 25-28], with the energy saving impact of feedback technologies varying modestly across the literature. Ueno et al. [27] monitored the energy use of 8 households in Japan pre and post the installation of an in-home interactive feedback display, finding an average 9 per cent energy saving in the first two months after installation. Darby [20] summarised the results of various feedback studies and noted that savings of between 5 to 15 per cent were associated with direct feedback displays. Faruqui et al. [25] examined a dozen North American and international pilot programs and found that energy savings range from 3 to 13 per cent, with an average of 7 per cent. Ehrhardt-Martinez et al. [26] reviewed 23 mostly North American programs and found that energy savings associated with real-time aggregate feedback typically fall somewhere between 0.5 and 18 per cent. Stromback et al. [28] investigated 74 energy feedback trials in Europe, North America, Australia and Japan reporting average savings of 8.68 per cent for in-home displays.

The amount and type of displayed information are important factors in the success of achieving energy savings [22, 26, 29]. Darby [22] and Ehrhardt-Martinez et al. [26] have found that ‘direct’ feedback, such as real-time energy use data, has a significantly larger impact than ‘indirect’ feedback, such as billing data provided after consumption has occurred. Ehrhardt-Martinez et al. [26] and Fischer [29] argue that greater savings occur when information is more frequent (current) and more detailed (disaggregated).

Ehrhardt-Martinez et al. [26] also noted a relationship between the energy savings impact of the study and the period of householder interaction with feedback information, finding that average energy savings tend to be higher for shorter studies (average 10.1 per cent) than for longer studies (average 7.7 per cent). This raises the issue of sustainability for energy use behaviour change due to direct feedback systems. Ueno et al. [27] found that energy saving behaviour extended beyond the technology associated with the direct feedback information, demonstrating that in-home feedback displays help householders become more energy literate and develop new behaviour patterns. For the small sample of houses in their research, Ueno et al. [27] found that total energy use of the appliances displayed on the feedback system was reduced by about 12 per cent whilst the total consumption of the not-displayed appliances was reduced by about 5 per cent.

The literature also identifies different levels and types of energy savings. Ehrhardt-Martinez et al. [26] found three categories of action: 1) simple changes in routines and habits, 2) infrequent and low-cost energy stocktaking behaviours (i.e. replacing incandescent bulbs with CFLs), and 3) investments in new energy-efficient appliances, devices, and materials. The study noted that most of the energy savings achieved through feedback programs resulted from changes in behaviour rather than investments, although greater savings were achieved by those households that invested in new technology.

The literature shows that households can react quite differently to the availability of energy use feedback data [30]. In a study of various in-home feedback display devices in Sweden, Vassileva et al. [30] found that 47 per cent of the participants interacted with the display quite often, while 19 per cent of the participants never consulted it. This study also found that the use of energy feedback displays with low-energy use households might, in some cases, cause an increase in energy use.

The Australian specific research into the effectiveness of in-home energy feedback displays is reasonably limited with results available from only two small-scale surveys, both of which are limited because the sample households were in the early stages of interaction or had virtually no experience interacting with the newly installed technology [31, 32]. This paper provides an opportunity to survey a larger group of households, most with multi-year experience interacting with in-home energy feedback displays.

Methodology

This research was based on the analysis of quantitative data collected from installed monitoring systems, and the analysis of qualitative data collected from interviewing 10 resident households living in Lochiel Park.

Resident Interviews

To understand the experience and perceptions of residents, primary qualitative data was gathered through a set of 10 in-depth interviews, with residents selected at random from a field of over 60 candidate households who had lived at Lochiel Park for a period not less than 12 months. All volunteer households were owner-occupiers, who represent the largest resident type at Lochiel Park. Where possible all adult owners of the same household were interviewed together, but where this was not possible prompts were used to enquire into any differences likely between the adult residents. For households with children, additional prompts were used to enquire into their likely usage of the energy feedback display.

The semi-structured interviews [33], conducted ‘face-to-face’ in their home, utilised open-ended questions to provide a replicable focus on the research questions, and were designed to explore the experiences and perceptions of households.

The questions probed the experience of residents during the home buying and construction phases, their perception of thermal comfort and ease of operating a passive solar home, and their experience interacting with new energy technologies such as solar photovoltaics, solar thermal water heaters and the energy feedback displays.

To protect the confidentiality of the interviews, anonymous verbatim quotes are used to illustrate points. Elsewhere the original language used by interviewees has been incorporated into the paper, or paraphrased with a light touch to facilitate the clarity of the message.

The information collected from the interviews was triangulated through a comparison with the experience of the principal authors, who have interacted with almost all potential candidate households at Lochiel Park on related energy use research. The researchers have informally discussed the use of the feedback displays with residents separately, sometimes on multiple occasions. These interactions have been used to test whether the sample survey results are representative of the experiences of the total potential population. Comparisons are also made with the findings of the 2010/2011 series of Lochiel Park residents’ interviews and an associated survey [32]. This series of interviews was conducted during the early stages of the development of Lochiel Park when only around a quarter of the homes were occupied, and during a period when many residents were still establishing their household routines and behaviours, but nevertheless these interviews provide a valuable comparison with the more recent series of interviews.

Overview of Lochiel Park Monitoring Systems

The data presented in this study is based on monthly analysis of one minute interval data collected from the in-home displays installed in each Lochiel Park dwelling. Although the systems collect electricity, gas and water use, and electricity generation information, the focus of this paper is on individual household delivered energy, i.e. the difference between the onsite energy consumption and that generated onsite.

Each home is fitted with an ‘EcoVision’ brand monitoring system, which incorporates an in-home display, a programmable logic controller, and an array of intelligent meters and sensors [34, 35]. This monitoring system measures and displays the residents’ electricity, water and gas use, plus solar photovoltaic electricity generation, in real-time. This level of monitoring is referred to as *general* in the data reported in this paper. In addition, other information are monitored in 10 of the houses, such as the indoor air temperature and relative humidity, the electrical consumption of up to eleven energy services (including heating and cooling, lighting, laundry, etc). This is referred to as *detailed* monitoring. Table 1 summarises the data measured by each monitoring system. Detailed information is available in [34].

Table.1: EcoVision measured and calculated parameters for the general and detailed monitoring systems. Note (D) indicates digital, (A) represents analogue (4-20mA) sensors [35].

	Electricity (kWh)						Water (L)					Tank Level (%)	Gas (L)		GHG (kg)	Temp / RH
System	Solar (D)	Import (D)	Export (D)	Total*	Net*	Individual appliances (D)	Mains (D)	Recycled (D)	Hot Usage (D)	Mains Hot (D)	Rain*	Volume (A)	Mains (D)	Hot Water (D)	Greenhouse Gas Emissions*	Living , Lounge, Bed rooms (6 A)
General	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	×	✓	×	✓	×
Detailed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

A detailed monitoring system schematic is shown in Figure 1. The figure identifies the EcoVision touch screen, the programmable logic controller (PLC), the optical network terminal (ONT), the contactors, the interconnecting cables, and the various analogue and digital sensors. Note that an overview of the general monitoring system can also be seen in the figure, due to the common components (i.e. the 8 digital sensors surrounded by the dashed box). Raw data from each system is collected remotely each month.

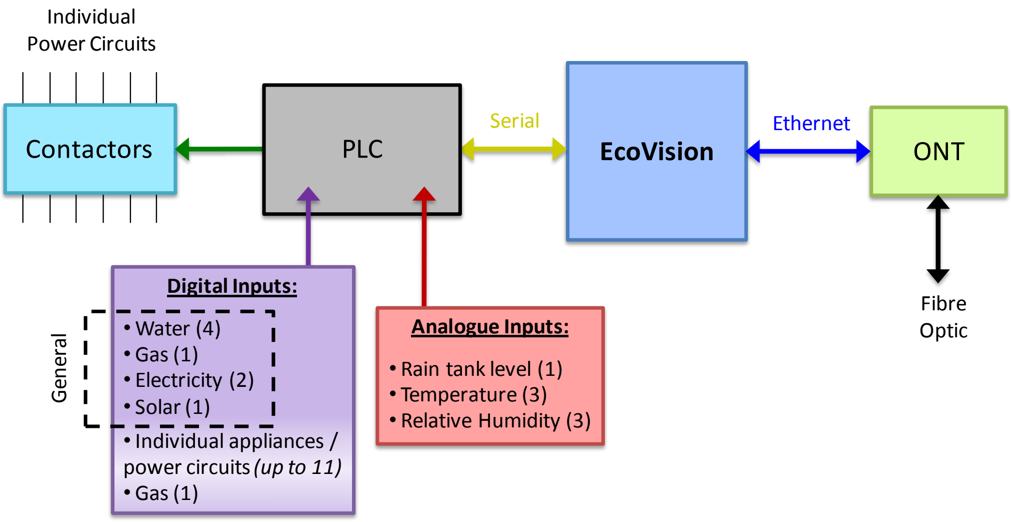

Figure 1: Overview of the detailed monitoring systems, showing various components. The dashed box represents the sensors used in the general monitoring system [35].

The system can also control the peak power demand by limiting it to a preset value. A feature of the EcoVision monitoring system allows peak energy demand events to be managed by interrupting the power supply to up to 6 individual power circuits or appliances by controlling specific contactors. The contactors are typically wired to appliances such as reverse-cycle air conditioners; pool or spa pumps; ovens and dishwashers, and power circuits such as laundry and kitchen, but not systems important to health and safety such as lighting and refrigeration. The load limit and the order in which appliances are deactivated are customised by the resident. The feature shuts down nominated appliances until the electricity load falls below the preset limit. Due to safety reasons, deactivated appliances are not automatically re-energised; this must be done by the resident manually. The Load Management feature is voluntary, and to encourage initial uptake the electrical retailer offered a small financial incentive to residents who maintained a 3kW limit at all times, however, this incentive is no longer available.

The heart of the EcoVision system is the in-home display which offers residents direct feedback, and real-time monitoring. The touch screen allows users to quickly summarise their consumption by time period and type of fuel / water, for any desired hour, day, week or month. Data is displayed numerically as well as in bar charts. The *detailed* monitored systems also offer a small degree of electrical energy consumption disaggregation, by breaking down how much energy is consumed by specific appliances or power circuits. Figure 2 shows a summary of electricity consumption and generation for one day.

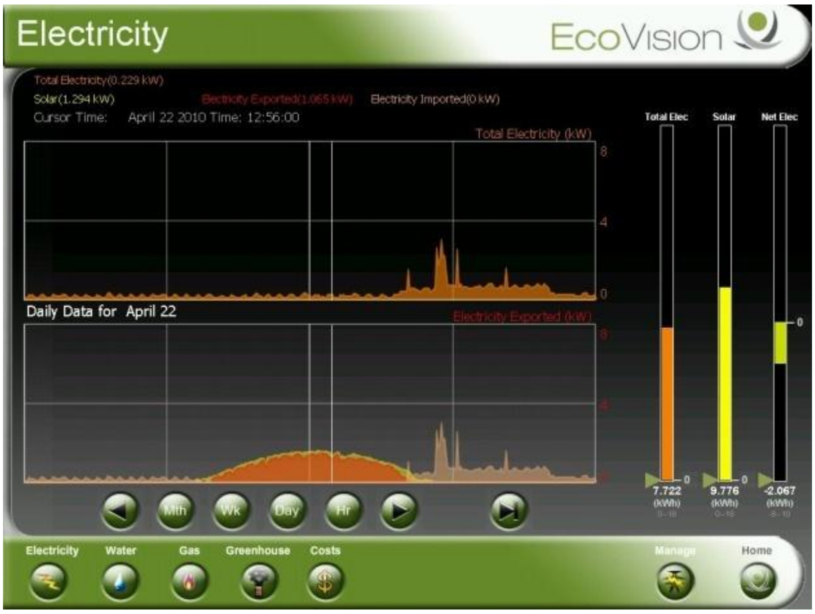

Figure 2: EcoVision screen, showing electricity consumption and generation for a period of one day.

The EcoVision system not only provides real-time information, it also allows users to compare their energy use and generation historically by month, week, day or hour. It also has the capability of converting the energy consumption to associated greenhouse gas emissions. Currently the system does not allow residents to directly compare results against other residents' usage or estate averages.

The EcoVision system consumes about 38W continuously (0.92kWh per day). This means that an amount of behaviour change is required before the system is of net energy and economic benefit to households.

Energy Performance of Lochiel Park Homes

Figure 3 shows the average delivered energy for the entire estate over a 12 month period. The dashed blue line represents the estate's average, and shows the monthly standard deviation as vertical bars, whilst the red dots represent the average of the households interviewed in this study. The close agreement between the two averages indicates that the interviewed households are broadly representative of the estate as a whole. Note the number within the round brackets of the x-axis represents the number of households within the estate for which data is available to calculate the average. This number generally increases over the monitoring period as newly constructed houses are connected to the monitoring system, however, in some instances the number slightly decreases due to intermittent data collection system problems.

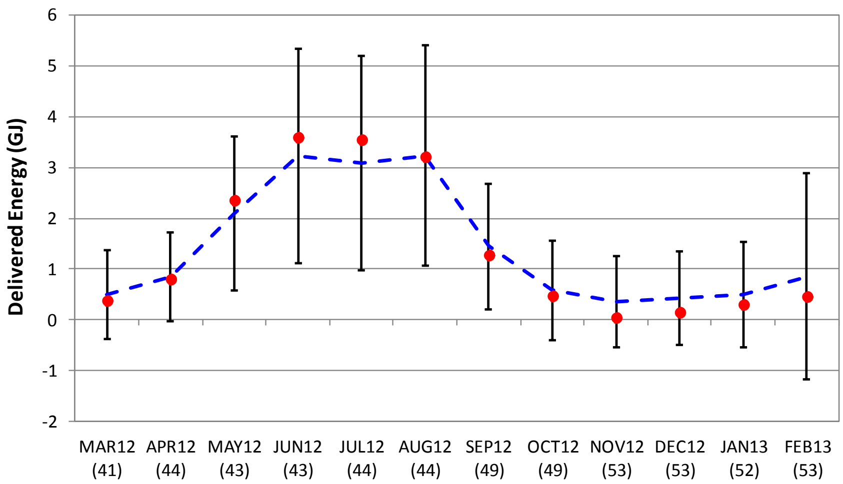

Figure 3: Average monthly delivered energy for Lochiel Park households (blue dashes), and for the subset of interviewed households (red dots).

Figure 3 also highlights three key features. Firstly, some Lochiel Park households are operationally net zero or below zero energy for summer months and those months immediately pre and post summer. Such a result demonstrates the successful application of low energy house design and fitout for temperate Australian conditions. Secondly, the average of the interviewed households is similarly zero or near net zero energy for those months. Thirdly, the large standard deviation span, particularly for winter months and late summer (February), indicates that there is a significant spread in net delivered energy for some households. This is despite the many common design and resident characteristics and energy system fitouts.

Figure 4 below shows the net delivered energy per month per resident for each of the interviewed households. After normalising for the number of residents in each household, the monthly delivered energy varies significantly between households, possibly indicating different energy consumption behaviours and/or the impact of differences in patterns of use and efficiency for particular appliances and equipment. In general, each house follows the same trend of higher delivered energy in winter months, most likely due to a combination of significantly lower solar photovoltaic electricity generation, higher artificial lighting use, and higher heating demand. Note that some of the interviewed households are missing data points, due to intermittent monitoring system faults.

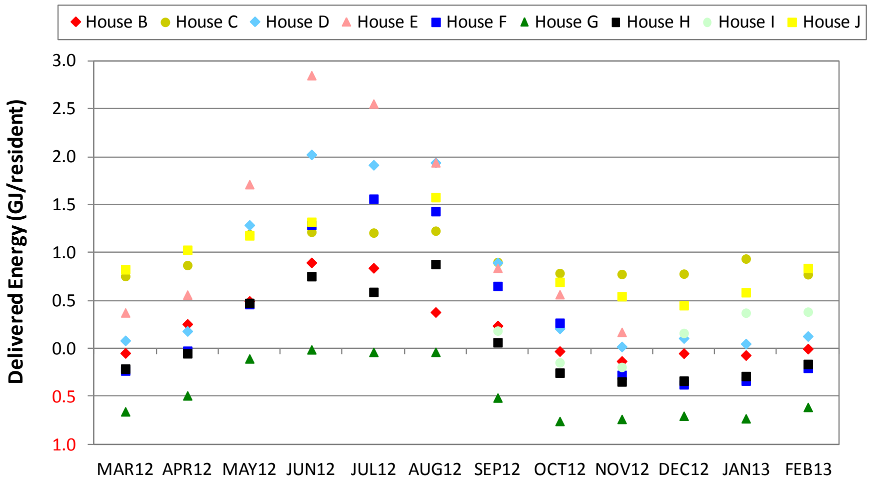

Figure 4: Normalised average monthly delivered energy per resident of the interviewed households.

Figure 4 shows that three of the interviewed households achieve below zero delivered energy for six months of the year, whilst another achieves this for five months. In addition, the figure highlights two key features: firstly, Households D and E require higher amounts of delivered energy in the winter months. This is probably due to use of gas space or underfloor hydronic heating, whilst the remaining households utilise reverse-cycle air conditioners with a high coefficient of performance. Secondly, Household G consistently achieves operationally net or below zero energy performance. This is probably due to the combination of frugal energy use, an all-electric house with high efficiency appliances, and a relatively large solar photovoltaic system to offset expected electrical loads.

Comparison with other Households

Although the results from Figures 3 and 4 demonstrate that some Lochiel Park households require near zero delivered energy for either part or full year periods, the performance of these households should be compared with other existing data sets for similar homes and similar climates to properly gauge their performance. Figure 5 compares the delivered energy of the interviewed houses per habitable floor area, with existing data collected by the research team for a nearby new housing estate (Mawson Lakes, MLK) in 2002/03, and with current state (SA AVG) and Australian (AUS AVG) national averages [34]. Note that the total delivered energy for Houses E, I and J has been extrapolated to correct for incomplete data sets.

Figure 5 demonstrates that Lochiel Park households require significantly less delivered energy compared with the monitored sample of new homes from the Mawson Lakes estate, and compared to both the state and national averages for all households (including apartments, units and holiday homes).

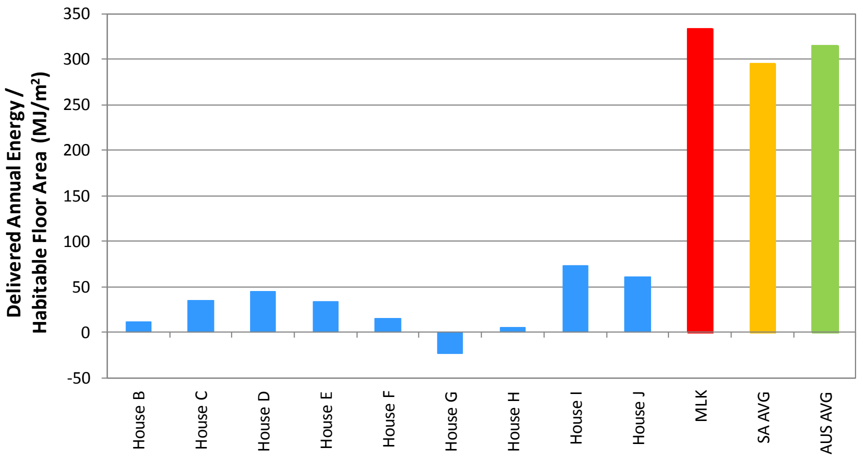

Figure 5: Delivered annual energy per habitable floor area for the interviewed households, a sample of Mawson Lakes households, and both state and national averages.

Interview Findings and Discussions

The level of interaction between the households and their in-home energy feedback display varies widely from no engagement, to occasional use, to multiple daily interactions. Differences can be observed across gender and age, with females less likely to use the display, and older (retired persons) less likely to have high frequency (daily) interaction with the feedback system.

The majority of households (6/10) had daily interaction with the feedback display, 3/10 households had occasional interaction and one household never interacted with the display. These figures hide differences between genders, whereby almost all male adults (9/10) interacted with the feedback display, yet 4/10 female adults stated they had no regular interaction with the display. The response from Household E characterises a reasonably typical level of interaction with the feedback system:

> *I think it's useful, I value having it there, I look at it most days.*

The frequency of interaction is slightly lower than that noted in the previous study [32], which found 80 per cent had daily interaction, but this may be explained by the novelty of the system wearing off with residents. Our research found a perception that use patterns have changed since the initial period of interaction, with half of the households suggesting they use the display less now than in the first 12 months of having the system available. One household felt that they have increased their usage of the display as they have grown more comfortable and confident using the system and the information provided. Household H represents the majority perception of usage changes, stating:

> *Less, a lot of it's the curiosity and learning the patterns of our usage.*

The Edwards and Pocock [32] research was conducted during the first months of occupation for the first tranche of Lochiel Park households, and changes to interaction frequency have most probably occurred as households settle into their new home, lose some of the initial curiosity with the display, and become more familiar and comfortable with the various energy technologies and the pattern of their use.

Very few households (2/10) keep detailed tracking of daily energy use and electricity generation, manually transferring data from the feedback display to separate spreadsheets. Other users more casually track energy use and electricity generation. Household J used the monitored energy data to help predict the size of their next energy bill. Household B represents a high frequency user, revealing:

> *'I love the touch panel. I keep an ongoing spreadsheet of all our daily solar generation and electricity usage.'*

Most higher frequency users asked for wireless local area network or Bluetooth compatibility to allow data downloads to other devices. Almost all households (9/10) considered some value in having the feedback information available on other devices such as mobile phones, tablet or laptop computers, particularly so data could be checked when residents are away from the house (i.e. at work or on holidays). Some households suggested greater value could be gained from the feedback displays if they could facilitate other activities such as linking to the internet, or allow settings for their solar water heater to be altered. Some users expressed frustration that variables such as energy prices and the time-clock could not be altered by residents, reducing the accuracy and usefulness of the output information.

The feedback displays were most often used for checking electricity usage, electricity generation from the solar photovoltaic system, and to a lesser extent, water usage. The residents of a detailed monitored house also monitored the amount of water available in the rainwater tank, using their display. One household found the gas data confusing. Household B expressed a desire to use the data to track the deterioration of photovoltaic panels over time. The monitored data was also used for fault identification, with five of the households mentioning how the in-home feedback display was helpful in identifying system failures or underperformance. For example: Household F checks the solar generation data on a regular basis to ascertain whether their DC/AC inverter is still operating, as a response to the original inverter burning out.

Several households thought that comparing their energy and water use with others in the Lochiel Park estate would be useful. Household C suggested a creative competition to encourage behaviour change by having an energy use challenge across the estate, with households able to see the energy use patterns of other Lochiel Park households.

Most households (7/10) felt that the system was easy to use, although comments were made from some who felt the software was not intuitive. This finding is similar to that of Edwards and Pocock [32] who found 80 per cent of households perceived the feedback displays to be easy to use. Household C provides a typical response to the question of ease of use:

> *Yeh, not a lot to it really.*

Several households suggested that some of the information provided was confusing, particularly the time axis information which doesn't show the actual time of use. This may limit the user's ability to recognise the relationship between specific technology use and energy use. Household H stated:

> *On the timescale it's not registering the time of day, so I can guess when the graph timescale is. I can see the beginning of the day and end of the day …*

Few (3/10) households had attended a training session, with 6/10 suggesting that either more guide material or training would be useful.

The Load Management feature of the system was not being used by any of the households. Many households thought that feature was no longer operating, others thought the feature was of little value to them for they were already very energy efficient. Household B did not use this feature because they wanted to maintain control of all electrical appliances and equipment. Household E had used the feature but found it 'useless' after it turned the washing machine off when they needed the clothes washed. Household G attempted to use the feature without success. Household I thought it was 'conceptually fantastic, but not a good feature at the moment', and referred to a negative experience of another Lochiel Park household that was not interviewed in this study. Household F was typical of responses to this feature:

> *[person's name] did mention that and explained it somewhat, but we haven't sort of run into that territory where we've been motivated to need to do it, …*

The majority of households (7/10) believe they have modified their behaviour due to their interaction with the feedback system. And although the quantum of behaviour change could not be determined with any confidence through the interview process, two of the households suggested their behaviour changes were relatively small, but others have achieved larger savings. Household D noted that they disposed of an old second refrigerator because it used too much electricity for the pleasure of providing cold drinks. When asked about behaviour change Household J felt the feedback system had been instrumental in helping them alter their energy use behaviour:

> *Yeh, definitely; the last two billing periods we have really examined what we using and how we are using it and have made some significant changes.*

Other households were not as positive about the affect of the feedback display of their energy use behaviour. Similarly Edwards and Pocock [32] found that some households considered their behaviour to be reasonably energy efficient and suggested that their behaviour would not be greatly affected by the feedback display. This type of response was identified in our interview series, with Householder I stating:

> *'We're here because we already were wary of our behaviours, we had already taught ourselves to conserve power .... Our behaviours had already changed, and they go on changing as we read more and we live in our house, but the screen is not part of that.*

The displays provided a variety of other benefits. Several households noted they use the feedback data to maximize their economic return from the local solar feed-in tariff, by reducing electricity use during photovoltaic generation hours and maximising export to the grid when electricity is at its highest value. Household C has used the feedback display to determine the energy use change associated with installing standby-load reduction technology.

The display was also being used as an educational tool, both to other members of the household and to visitors. Both Households D and G noted the value of showing the display to visitors.

An issue expressed by many households was the importance of service to maintain and repair the in-house feedback system. Several households talked about sensor faults, poor levels of response from the display provider, the slow process for software upgrades, and the lack of technical support. Household J raised the question of whether the system will be maintained for the life of the house.

Overall the value of the in-home energy feedback system is reflected in the number of households that wish to have a system in their next home. Six out of ten households suggested they would like a feedback system in their next home, although not all wanted the same brand of monitoring system, and one household qualified the response with concern about the system's affordability. On the whole there was sufficient interest to suggest the majority of households valued having live energy use and electricity generation monitoring in their home.

A larger sample of Lochiel Park households will be interviewed or surveyed to gain further understanding and insight into the experiences of residents and their in-home energy feedback displays. The larger sample size will facilitate a broader range of both quantitative and qualitative analysis investigating relationships between energy usage and other factors, such as demographics, frequency of interaction with displays, perceived need for energy services, and perceived energy use behaviour change.

Conclusions

The paper has provided integrated technical and social research on the outcomes of a world class model green village which demonstrates how building design and practices, energy efficient appliances, renewable energy technologies, and household behaviours may lead to a more environmentally sustainable lifestyle. The Lochiel Park development includes the first large-scale residential development in South Australia with in-home energy feedback displays.

Detailed energy use and electricity generation monitoring has demonstrated that households in the Lochiel Park Green Village use substantially less delivered energy than others residing in new homes in the same climate.

A series of ten household interviews, backed by informal discussions with over fifty households, provides a new insight into the interaction of residents with in-home energy feedback displays. This new research is compared with data collected from the first tranche of households arriving at the same housing estate.

The research has found that the majority of households interact regularly with the feedback displays to examine their energy use and solar generation, but a small number of households have little or no interest in drawing on the available energy use information. Most households, even some who rarely use the displays, find the system easy to use.

Households perceive that the frequency of use has lessened over time as the curiosity wanes and they establish more regular patterns of energy technology use, but many households maintain daily interaction.

The load management feature of the system is not being used by any interviewed household, and few considered the feature useful. This is not surprising as there is no current financial incentive for limiting the peak demand.

The evidence from the interviewee perceptions is that the energy feedback displays assist households to reduce their energy use and identify energy system faults, although the quantum of energy saving is difficult to ascertain. Most households considered the feedback displays to be valuable tools and indicated they would most likely install similar technology in a future home.

The response of interviewees indicates that further research should be conducted by the feedback display system developers to ensure the information provided is easy to understand, provides useful comparisons, and the software navigation is user-friendly. Feedback display system developers should also consider minimising the system's energy demand, which would reduce the amount of behaviour change that is required before the system is of net energy and economic benefit to households.

The research has found that in-home energy feedback displays may play a useful role in supporting and encouraging energy use behaviour change, leading to lower energy use.

Acknowledgements

The authors wish to acknowledge the funding and support provided by the CSIRO's Intelligent Grid Cluster. They would also like to thank the support and information provided by Renewal SA, in particular Andrew Bishop and Phil Donaldson. Finally, the authors wish to thank Dr Anne Sharp for her valuable advice and assistance in shaping the Lochiel Park residents' interview design.

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Home Automation for a sustainable living – Modelling a detached house in Northern Finland

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Abstract

This paper presents a model of a detached house in which home automation has been progressively introduced into the building. The model integrates different factors related to end-user behaviour and decision-making regarding the management of electrical energy consumption, and integrates a gradual end-user response to home automation measures. The presented model aims to show the potential economic benefits obtained by the modelled changes of end-users' behaviours within a smart energy network based energy system. Matlab/Simulink is used as a simulation tool for representing the model in which a 10 year database of Nordic climatic data has been built in, on an hourly and half hourly basis. The modelled building environment comprises twenty-one appliances and two lighting systems with different power rates. Each appliance and light bulb is individually measured. The feedback methods assessed were self-comparison, inter-comparison, and a target based system. The effect of home automation on energy consumption at the building level is assessed, and the importance of end-users in energy reduction is highlighted. The model categorises "green" and "brown" energy users and integrates their behavioural profiles within the end-user response. As part of a smarter electricity management system, the home automation system is able to interact with other buildings, either in terms of geographic or building infrastructure similarities. This will enable taking or modifying decisions at any given time, thus contributing to the local flattening of power demand. Such systems must work hand-in-hand with the grid operator.

1. Introduction

With the massive deployment of smart meters across Europe allowing digital measurements, energy companies and Public Institutions have access to a consequent database of energy consumption data throughout a country. European Union (EU) Member States have the obligation of implementing smart meters covering 80 % of consumers by 2020 at the latest [1]. In contrast to European Directive 2012/27/EU [1], Finnish legislation (18.1.2013/50) sets a deadline of 2014. The deployment of smart meters also brings up the issue of data security and use of the collected information, in particular in relation to the role of energy utilities and Public Institutions [2]. Legal obligations to increase energy efficiency also provide a motivation to the deployment of renewable energy sources, as a vector for energy production, and an increase in the energy efficiency of buildings. Home energy management can have a significant role in contributing to energy efficiency and cutting down peak load. This can be achieved through an active collaboration of energy consuming systems and the information network e.g. at the local level [3], [4]. Putting together the different factors mentioned involves the development of a smart energy network (SEN), capable of managing the energy system through constant monitoring.

SEN can be seen as a multi-layered configuration of the energy infrastructure, within which smart buildings are at its foundation [5]. Within a SEN architecture, the energy network is split into multiple complexes, forming a set of networks that communicate between each other [6]. Each horizontal area belongs to the same layer and vertical area to different layers. Energy and data may travel horizontally and vertically but not in diagonal. The main objective in this context lays in an increase of energy efficiency along with an economically viable reduction of environmental impacts where home automation has an important role. The effect of energy efficiency on the decrease of energy consumption at the local level is often offset by the rebound effect. The direct rebound effect, which is affected by the variation of the home energy budget, shares a responsibility in the success of energy efficiency measures [7]. Analyses of energy end-use at the home level become necessary for structuring a bottom-up system.

For the past fifteen years, surveys of energy consumption habits have been carried out across European households. Most of the surveys were looking at the effect of energy feedback to end-users' behaviour ([8-11]). Earlier work [6] showed that retrieving feedback regarding end-users' energy consumption could affect positively the overall impact on energy efficiency. An average decrease from 4 to 20 % of energy consumption has been found in the literature [12].

Modelling daily energy demand has been tackled from different angles in a top-down and bottom-up approach. A non-exhaustive list of these models have been described in [13] showing details of the different ways for representing the energy consumption in households. The timescale represented in previous models goes from hours to minutes [14-16]. In order to have a detailed energy profile, the bottom-up approach appears to be the most suitable method, compared to a top-down approach, where the overall energy consumption is broken down to individual appliances [16]. Modelling the energy consumption profile generally uses measured data from field tests as input data [13], [17]. Depending on the method used, energy consumption may be simulated from a human perspective by creating occupancy scenarios that will enhance the use of appliances. Grandjean et al. [13] pointed out the difficulties of such a technique, as it requires an extensive database on human behaviour and the activities undertaken. It is preferable to find a solution via the pattern of appliances' usage and deduce from it the human activity within the household. A comparable approach has been carried by Borg and Kelly [18] for evaluating the impact of appliances on energy efficiency in the future. They have not considered either the probability of an event or action occurring in the eventuality that home automation through smart metering would be applied in dwellings.

Modelling an energy system from the bottom up, more appropriately takes into account distributed energy systems [19] as an alternative to centralized energy production systems. Such energy architecture is being developed in parallel with the development of micro- and small-scale energy production systems [20]. Currently, Finland is considered to be a centralized system but has a considerable potential for having a decentralized system.

This paper investigates a bottom-up approach model centred on the use of appliances. The first part highlights the model description and its architecture. The second part details the data collection involved in order to run the model. The third part illustrates the model with the results obtained. Validation of the model puts in perspective the obtained results with real time energy consumption data of typical Finnish detached houses from the Oulu region.

2. Model

Structuring a model with a bottom-up approach requires detailed information regarding the studied living environment. Stokes [21] introduced a widely used system taking into account specific information related to the appliances, the socioeconomic status of the occupants, and a large panel of measured data as the basis for a statistical analysis of the energy profile. The energy system built with the bottom-up approach thus requires a precise, pre-defined system that creates a consequent database.

The model presented in this paper is based on an hourly scenario of appliance and lighting use. Based on a pre-selected number of users, their housing types, and the corresponding number of rooms, the model describes the usage of twenty-one pre-defined appliances. The lighting system presents two technological alternatives (incandescent and low consumption bulbs) in order to describe the energy consumption related to a lighting system. The model associates pre-determined energy consumption with the usage of different appliances (Figure 1). This is based on the assumption that, in order to use some of the appliances, a given number of persons are expected to be in the house, therefore consuming a statistically pre-defined amount of energy.

The user behaviour is evaluated depending on the feedback strategy chosen for the simulation. Feedbacks are dependent on the controller side of the model, which is used as a statistical tool. In this model, feedbacks are based on the self-consumption, the inter-comparison and the target based system.

The controller allows the piloting of certain appliances that are flexible over time, such as the washing machine and the dishwasher. The controller crosschecks information with the grid and between appliances in order to electrically decrease the power demand of relevant appliances during peak load hours.

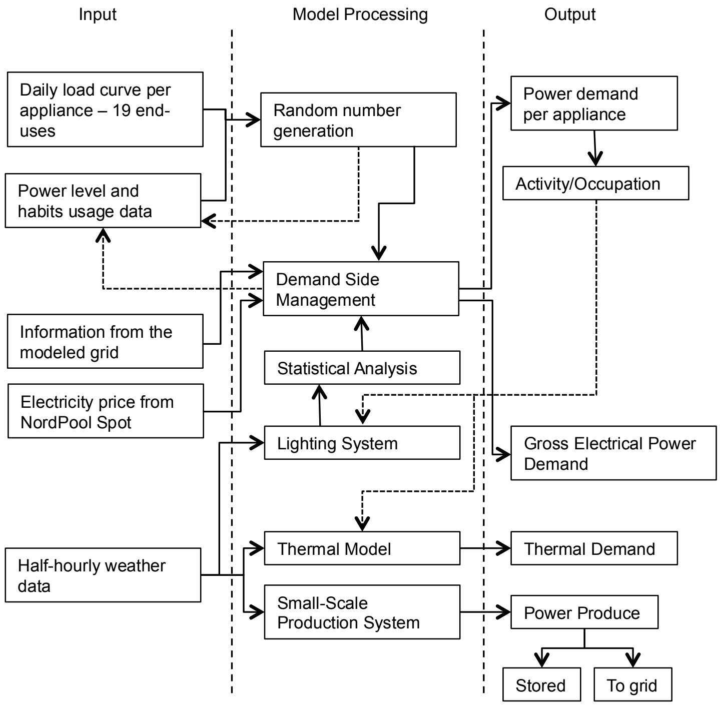


Figure 1. Block diagram of the model developed (based on [13])

2.1 Scenario Architecture

The model is built on an hourly basis using statistical results from earlier research [6].Firstly, the user behaviour regarding the use of appliances follows results coming from the Energy-using Product (EuP) [17] surveys on energy efficiency and use. These large-scale surveys intended to pattern the use of appliances in order to settle the energy efficiency rating scale under the European Energy Efficiency Directive. An example of data that can be extracted from these studies is shown in Table 1 which shows the different number of washing machine cycles that occur during the week per inhabitant. In the case of a washing machine, the type of program as well as the mean time for carrying out the action is given. Other information such as the average energy use per year or information that belong to specific appliances (e.g. mean recharging time of a mobile phone) is provided. These data set the model boundaries.

Table 1. Time of use and probability of activity occurrence for a washing machine

	Nbr of wash/week
1 person	2.1
2 persons	3.4
3 persons	4.9
4 persons	6.4
5 persons	6.3
6 persons	7.0

Temperature	Distribution	Time [min]
Cold	02 %	35
30°C	09 %	40
40°C	49 %	45
50°C	07 %	50
60°C	27 %	60
90°C	06 %	70

The second part of the model consists of tracking the daily energy profile of each appliance. In order to understand how an appliance is used, results from the REDMODECE [3] European Project have been processed to give mean daily energy profiles for the twenty-one appliances used in this model. To create these vectors, empirical values from multiple surveyed houses have been extracted from comparable Nordic countries (Norway and Denmark). In addition, it seemed relevant to integrate in the model the use of a sauna, considering that, in Finland, there is an average of 0.38 electric sauna stoves per capita [22]. Therefore, field data and/or assumptions for sauna stove use were added.

Figure 2 indicates the daily usage of the abovementioned electric appliances. Each plot represents the probability function for an appliance to be used over the course of a day. This explains the very high occurrence for some appliances such as a hair dryer in certain periods, due to the low probability of use another time of the day. Note that the hairdryer and iron peak at 56 % and 33 % respectively.

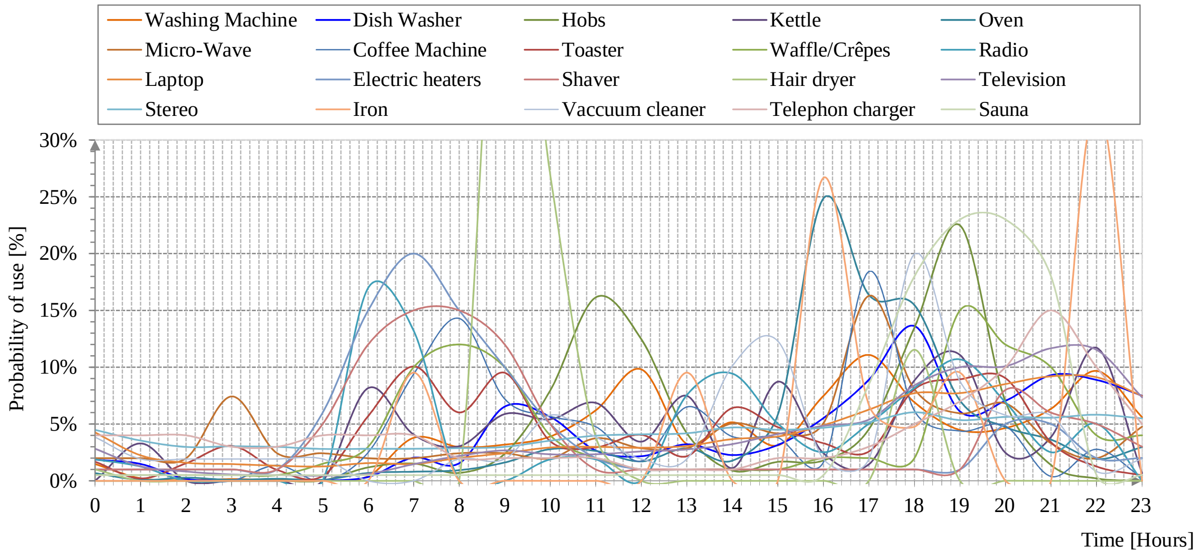


Figure 2. Daily energy profile for twenty-one appliances extracted from electric measurement

Once the profiles have been drawn out, daily and weekly safeguards are defined limiting the usage of an appliance [6]. Equations (1-4) express the conditions to be verified in order to have a confirmed action at t = n.

$$\overline{A}_{d-1} < \frac{2}{7} A_{w-max} \quad (1)$$

$$\text{and } \overline{A}_{w-1} < 1.1 A_{w-max} \quad (2)$$

$$\text{and } C_{h\,n} < R_h \sim U(0,1) < C_{h\,n+1} \quad (3)$$

$$\text{and } R_d \sim U(0,1) < C_w \quad (4)$$

Where $\overline{A}_{d-1}$ is the mean activity of the previous day, $\overline{A}_{w-1}$ is the mean activity of the previous week, $A_{w\text{-}max}$ is the maximum weekly activity as defined in Table 1, C_{hn} is the probability of use at t = n and $C_{h\,n+1}$ is the probability of use at t = n+1, C_w is the probability that an action will occur over the week or the weekend, R_h~U(0,1) and R_d~U(0,1) are uniform random numbers generated for the hourly and daily activities respectively.

The usage model of appliances allows the occupation within the detached house to be defined, which is also used for the lighting model. The available luminosity is calculated following solar irradiation. The relationship between solar irradiation and luminosity has been empirically established by Yokoya and Shimizu [23]. The lighting model is built using three components; namely the activity/occupation scenario, the available natural luminosity, and the luminosity required to carry out a certain task. Combining these three factors establishes the probability of use of light between 10% and 100%, where 10% is the probability of using artificial light on a very clear day and 100% is the probability of using light when the natural light is non-existent.

2.2 Demand Side Management

Including the user response within the model required the use of a demand side management (DSM) model. Consumption data are used for statistical purposes, monitoring the average appliance usage with reference values [17] on daily, weekly, monthly, and yearly levels.

These average consumption data are used for self-comparison and giving information to the end-users if they have over-consumed compared to the four reference levels. Independently from the user type, the fact that the end-user does not reach the level of consumption from the previous reference period (weekday, week, month or year) increases the acceptance of consuming energy at t = n [6].

The target-based system uses the previous data to build up the target for each dwelling (in case of multiple dwelling in the simulation). The tolerance for energy consumption increases or decreases depending on how well the end-user has performed at each iteration.

For both the self-comparison and the target-based system, the user response follows three trends, depending on the nature of response to the advice coming from the DSM system. A “green” user is considered to have a high positive response to the advice due to his/her personal background. In this context, such user is considered to have a standard positive response of 70 %. Similarly, an “orange” user will have a 50 % positive response, and a “brown” user a 30 % positive response. It is considered that a user would not have a 100 % positive response to any of the advice coming from the DSM system. The DSM ponders the standard response. Depending on the electrical consumption and the advice that the DSM may give, the standard response varies by up to +10 %. The user response will affect three variables related to use of the appliances: reducing the time of use of an appliance by integrating low-cost energy efficiency measures i.e. e.g. covering the pot, reducing the use of light; shifting the use of an appliance to an alternative time in case of peak load hours e.g. the use of the dishwasher during the night. In this case, the shifting requires the consent of the end-user but the time of the action is controlled by the automation system; and shifting the use of the sauna up to 1 hour in case of peak load. In the case of shifting the sauna use, the agreement of the end-user on actually agreeing on offsetting the use of the sauna from the traditional hour to another one is required. Therefore, it has been assumed that the end-users will not agree on taking a sauna in the middle of the night but would rather change the traditional sauna time by 30 minutes up to 1 hour.

The control system integrated in the model is capable of automatically postponing an action for specific appliances such as the washing machine or the dishwasher to any given time. It is highly unlikely that a control system would ever automate the use of all appliances in a household, thus a restriction to these two appliances has been made. Furthermore, in case of peak load time detected on the grid, the household control system is capable of reducing the power demand of appliances that require high power e.g. kettle, and iron. In these ways, the household power demand is reduced and a decrease in the peak load at the grid level is expected. Decision-making by the control system is currently based on the price information that it is receiving from the grid. In the case of a fixed-price system, critical hours are perceived during the high price period. In case of real-time pricing based on the electric spot price system, a combination of the real-time pricing and the price forecast is made in order to define the peak load time and thus apply a reduced power demand from the appliances.

3. Data collection

Running the model requires the use of reliable data, including the price of electricity on the energy market, the power levels for each appliance that defines the quality and the age of the appliances, and the weather conditions on a regular basis. Each dataset was combined together into two monotonic increasing vectors of half an hour and an hour.

3.1 Climatic Data

In order to create a dynamic model, data on temperature, solar irradiation, wind speed, wind direction, relative humidity, sky condition, atmospheric pressure, wind chill, dew point temperature and visibility were retrieved from an online weather database [24]. Raw data were given for 30 minutes samples on average, meaning that data processing was a necessary step to have a uniform vector of data. The Finnish Meteorological Institute issued the global horizontal irradiation data on an hourly basis for the years 2004 to 2012.

For the years 2000 to 2002, large amounts of data were found to be missing. In these few cases, artificial data was calculated from the mean variation of a variable for the previous and the following year, with the reference value of the previous hour. In the case of most recent years, smaller amounts of data were found missing for up to 6 hours in a row. In this case, a linear interpolation between the two existing values was created. The full processed dataset can be found in [6].

3.2 Appliances Data

The power demand required for each appliance was defined following the Best Available Technology (BAT) defined in the EuP research tasks [17]. As long as the information was given in terms of kWh per year, the total working hours per year for each appliance were taken. The ratio between the total energy consumption per year and the total number of working hours gave an average power demand in expressed in kW. Furthermore, seven categories (from A to G) were defined in the EuP report, “A” being the most efficient appliances and “G” the least efficient appliances. In order to select a certain category of appliance to be implemented within the model, each appliance was divided into three categories: A/B, C/D, and E/F. Each category was assigned a median value of the power demand calculated using the previous method as summarised in Table 2.

Table 2. Rated power for each appliance used in the simulation

Based on the European Energy Label

House zone	Appliance	A/B Category [kW]	C/D Category [kW]	E/F Category [kW]	Standby power [kW]
Kitchen	Washing machine	0.306	0.410	0.520	N/A
	Dish Washer	0.929	1.250	1.600	N/A
	Electric Cooktop		4.000		N/A
	Kettle	2.000	3.000	4.000	N/A
	Electric Oven	4.000	5.000	6.000	0.005
	Micro-wave	0.950	1.200	1.400	0.005
	Coffee Machine	0.600	0.800	1.000	N/A
	Toaster	0.800	1.300	1.600	N/A
	Waffle/Crêpes	0.900	1.200	1.500	N/A
	Fridge	0.300	0.400	0.600	N/A
Bedroom	Radio	0.005	0.008	0.010	0.001
	Laptop Active	0.060	0.080	0.120	N/A
	Laptop Sleeping	0.003	0.005	0.010	N/A
	Laptop off mode	0.002	0.003	0.006	N/A
	Telephone charger	0.010	0.015	0.020	N/A
Bathroom	Electric heaters		1.500		N/A
	Shaver	0.010	0.015	0.020	N/A
	Hair dryer	1.000	1.200	1.500	N/A
	Sauna stove		6.000		N/A
Living Room	Television	0.125	0.150	0.200	0.005
	Stereo/Hi-Fi	0.080	0.100	0.120	0.001
Cleaning Tools	Iron	1.000	1.300	1.500	N/A
	Vacuum cleaner	0.700	1.200	1.400	N/A

3.3 Electricity price data

In order to integrate the price variation of electricity in the model, the public prices from the main energy retailer from the Finnish Oulu region (Oulun Energia Oy) have been compiled. Three contracts, offered from the same company, have been included. Each contract allows the end-user to choose what type of energy production system their energy comes from i.e. biofuel, wind energy or mixed energy. A fourth option was given to the end-user by selecting the real-time pricing system. A more complex system could be built in order to take into account the variation of energy demand on the network [25]. In this model, a method for creating the real-time pricing based on historical data has been developed. This approach requires the hourly price of electricity on the spot price market on one hand, and the average retailed electricity price to the end-user for the same period on the other hand. Both datasets are publicly available from the Energy Market Authority [26]. Using Equation (5) allowed the establishment of an hourly purchasing price for the end-user by correcting the spot price from its extreme incentive values, which can reach thousands of €/MWh on the positive side for some specific hours in order to increase energy production, and may be a negative price to reduce energy production.

$$P_h = \overline{P}_m \times \frac{P_{h-Network}}{\overline{P}_{m-Network}} \quad (5)$$

Where P_h is the hourly price of electricity for the modelled dwelling [€cent/kWh], $\overline{P}_m$ is the monthly average price of electricity for dwelling [€cent/kWh], $P_{h\text{-}Network}$ is the hourly electricity price on the spot price market [€/MWh], and $\overline{P}_{m\text{-}Network}$ is the monthly average price of electricity on the spot price market [€/MWh].

4. Results and Discussion

The model presented above aimed to draw daily energy demand profiles coming from the appliances plus lighting systems. Moreover, the implementation of home automation is included in the model with the aim of increasing the effectiveness and efficiency of the household's energy consumption.

The model used measured data in order to build up the scenario of energy demand. The modelled data were contrasted with real-time energy consumption measurements carried out in 16 households in the Oulu region in 2012 [27]. The mean daily energy demand profiles have been drawn for the entire year in the case of the modelled dwellings and a typical four-person family house in Oulu (Figure 3). General electricity consumption as well as the electricity price was taken every six seconds for each phase (in the case of three-phase houses). These houses had dynamic pricing following the spot price market. The electricity consumption recorded varied from 5 929 kWh/y up to 13 706 kWh/y for the period of January 2012 to January 2013. The mean daily energy profiles aim to recognize a tendency in the energy production for each dwelling. A common pattern in a Finnish home sees a peak of consumption in the evening due to the use of the sauna stove, which levels out the other peaks occurring during the day e.g. the morning peak.

The modelled house was set for the twenty-one appliances named earlier and all of the appliances were classified as being A/B labelled. As an indicator, the sauna stove used for the modelled house was set to 6 kW as mentioned in Table 2. The overall electricity consumption coming from the appliances has been found to be around 4 501 kWh/y which is correlated with the findings in the European ODYSSEE MURE project and by the Sähkötohtori Analysis [28]. The measured data were carried out in a four-family detached house (in Oulu, Finland), which is equipped with a 10 kW sauna stove.

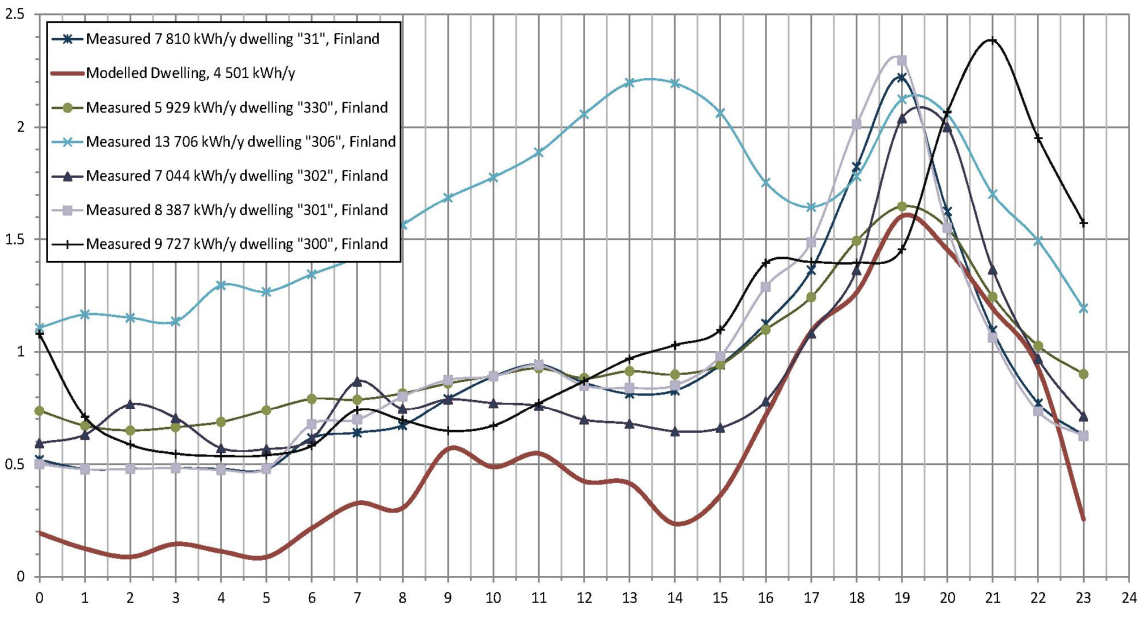
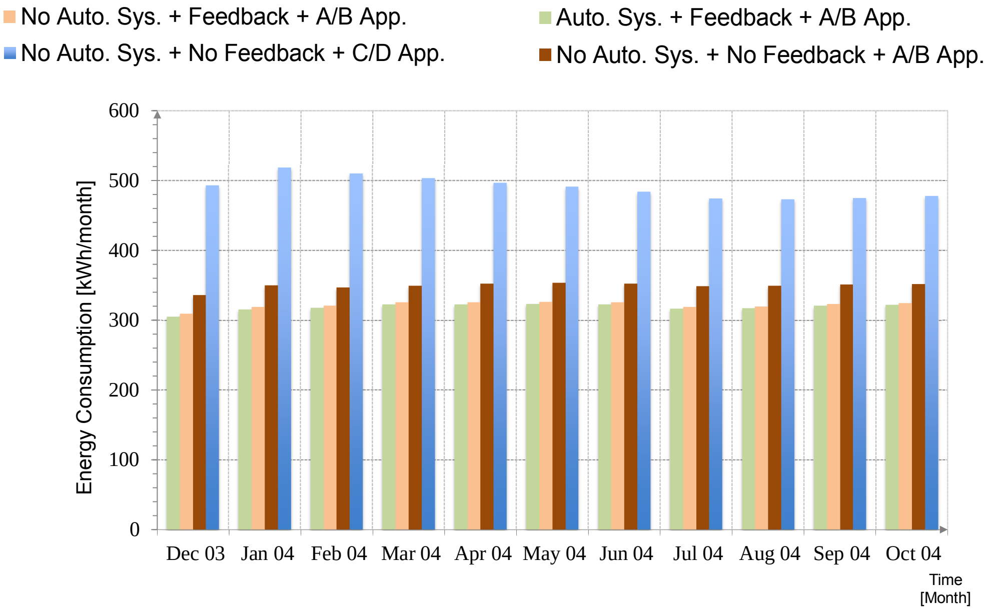


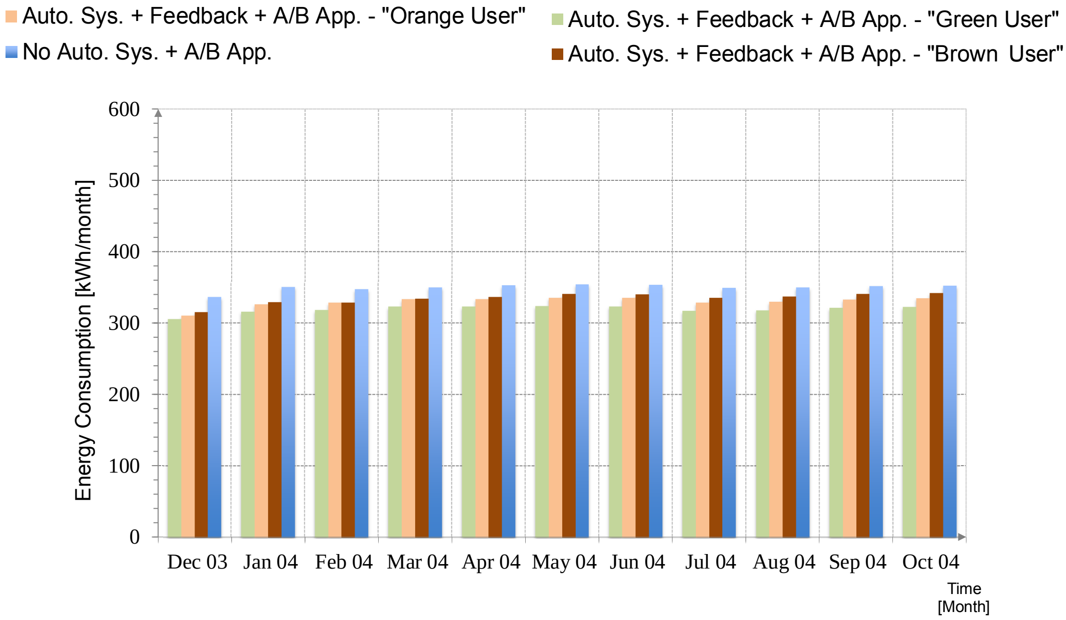
Figure 3. Comparison of a dwelling modelled with real time data measured in a four-person detached house in Oulu, Finland

It is not yet clear how the offset (of approximately 400 W of average power demand) shown in Figure 3 appeared. Our assumption is that it could be an electric under-floor heating in wet rooms, as is common in Finnish homes. This would be on constantly during certain periods of the year and it was not included in our model of the detached house. Earlier research has shown [6], [28] that the share of electricity demand for a secondary heating system may be considered as the highest proportion of electricity demand, reaching up to 50 % of electricity consumption of detached houses in Finland. Nevertheless, it can be pointed out that the trend of modelled mean power demand follows the trend of data collected in real houses, giving confidence in the model.

We focused on the change in energy consumption due to the introduction of energy efficient appliances (Figure 4 a.), and on the impact of user response on final electricity consumption (Figure 4 b.). The simulation showed a decrease in energy consumption of 30% using the same scenarios when all C/D labelled appliances were replaced by A/B labelled appliances. In the second stage, a feedback system was introduced in the model in order to simulate the effect of providing data information to people using self-comparison or a target based system. The simulation presented a decrease of the overall electricity consumption by 8 %, which is coherent with the findings from Ehrhard-Martinez [12]. In the last stage, the automation system allowing the direct control on the washing appliances managed to decrease the energy consumption by 1 %.



a.



b.

Figure 4. a. Consumption level by upgrading the technology installed in the dwelling, b. Monthly energy consumption level by user category.

Figure 4 b. indicates the importance of user response on energy consumption. The difference of decrease in energy consumption between the two extreme categories varies from 3.3 % up to 7 % depending on the month. Compared to the base scenario where no feedback system is installed within the home (the brown bar on Figure 4 a. and the blue bar on Figure 4 b.), the difference in electricity consumption between the base scenario and the scenario that considers a high positive response from the end-user may reach as high as 10.9 %.

In the context of flattening the daily energy demand profile, the model looked at the consequences of consumer feedback and home automation on the mean daily electric demand. The shifting of electricity from one particular hour to another one can be seen in Figure 5. On one hand, the electric consumption from 12am to 6am increased by 50 %. On the other hand, the electric demand from 7am to 12pm slightly shifted down from their original level. This longer period of negative shift supports the decrease of energy consumption over the day. This is explained by the feedback effect that influences the way appliances are used and offers up to 10 % reduction of energy consumption, compared to the original demand profile.

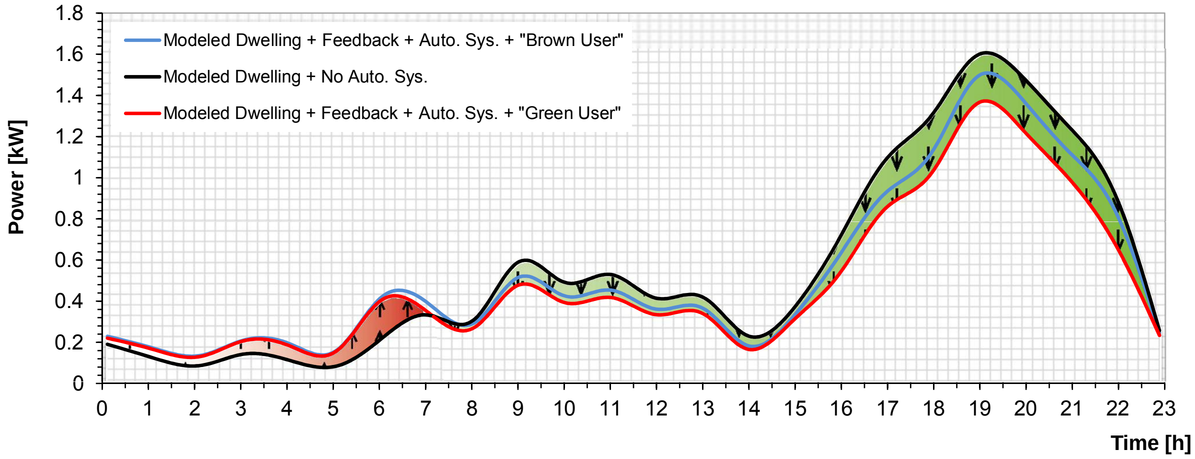


Figure 5. Effect of feedback strategies on demand profile and home automation in a detached house

The shift of energy demand seen in Figure 5 has to be balanced between the shift due to the automatic controller, and the one due to human behaviour. The latter is directly linked to user response and the way that end-users are utilizing their appliances at home. Thus, the “Brown User”, with its lower response and more frequent use of certain appliances may have a higher consumption than an end-user with a higher positive response when the system is asking to reduce the demand (see the Blue plot and the Red plot between 5 and 6 in the morning on Figure 5).

5. Conclusions, Recommendations and Future work

In this paper, a model of daily energy demand in a detached house in Finland has been set out. The model showed concordance with real data measured in a Finnish household. The model also integrated three types of user-responses as well as home automation, in order to control the use of programmable appliances. In terms of feedback impact, the model showed similar results to those found in the literature i.e. an average reduction of household electrical consumption by 8%. The automation system controlling the dishwasher and washing machine was able to decrease overall energy consumption by 1 %. In order to flatten the mean daily electricity consumption profile, some peak loads were shifted from the evening to the night period.

In order to fully use this model, it should be combined with a layered-grid model in charge of the energy management of multiple micro-grids. Such architecture should support a bottom-up approach of the electric infrastructure for creating dynamic pricing and managing the energy by geographical sectors. This model represents a starting point for evaluating the possibility to switch the mostly centralized energy system to a hybrid, mostly decentralized energy system. In this sense, the limitation of the model presented in this paper challenges to build up of viable scenarios involving dynamic pricing that would take into account the energy demand for building in the same geographical area.

Further work needs to be done in order to improve the model and get a better profile for each dwelling. Development should firstly focus on a minute-based electricity demand simulation, assuming that the output function would still be flexible enough to simulate a meter communicating hourly or daily data to the grid. Linked to the model, the daily energy demand profile per appliance will be varying in time, meaning that each appliance will follow the pre-defined energy profile and will evolve with the simulation time in order to integrate the end-user response and its effort for shifting the use of appliances in time. For integrating each aspect of energy efficiency, the direct- and micro- rebound effect should be integrated for each appliance and for the household. Finally, defining the appliances present in the households should depend on the end-user's definition within which appliances may be recurrent e.g. multiple TVs, video games and so on. In the future, the model should assess the impact of real-time pricing (hour-to-hour or minute-to-minute) on the peak load hours, and, its consequences on the electricity consumption by the end-users.

6. Acknowledgement

The authors would like to thank the Ympäristötili Pohjoista Voimaa foundation and the Thule Institute Research Programme for funding this research.

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Benchmark results towards energy efficiency in residential care homes for the elderly

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Abstract

The Energy Performance of Buildings Directive has been the driver for the establishment of energy performance ratings and certification in buildings. The development of benchmarks to compare the energy performance of similar buildings across different countries has been an important method to promote energy efficiency in buildings. While energy consumption benchmarks for office buildings have been already studied in several countries, no energy benchmarks are available for Residential Care Homes for the Elderly (RCHE). However, this sector is becoming more and more important as the population is ageing at an increasing rate. Estimates indicate that in 2050 the European elderly population will have doubled, reaching 60 million people. Moreover a recent research (Intelligent Energy Europe SAVE AGE project) found Care Homes lack knowledge and awareness on energy efficiency, and they are generally quite reluctant to adopt new technologies, since their main concern is to provide the best quality care possible. Therefore, there is a significant potential for energy savings in this area. The benchmark indicators presented in this paper are based on data collected from monitoring 10 RCHE in each of 10 different Member States (MS) participating in the study. The monitoring was based on a detailed survey assessment, followed by a computer modeling that used a multivariate linear-regression approach to model the energy consumption data and correlate different energy usage indicators. Heating Degree Days (HDD), net area, year of construction, number of residents, and number of employees are selected as the factors that may influence the energy consumption of a building. User behavior has also been analyzed but was not considered for the benchmark. The results show that HDD was not the most important factor influencing the energy use intensity but rather total conditioned area and number of residents. However, energy consumption used for heating purposes per resident per year has a positive correlation with the HDD.

Introduction

The European Council of March 2007 emphasized the need to increase energy efficiency in the European Union (EU) and to reduce the EU’s energy consumption by 20% by 2020 compared to projections. Therefore, an energy efficiency action plan was created and MS have identified significant potential for cost-effective energy savings in the buildings sector. The Energy Performance of Buildings Directive (EPBD 2002/91/EC) has been the driver for the establishment of energy performance ratings and certification in buildings by MS. Shortcomings in that Directive led to a recast to improve its effectiveness and set things more clearly. On 19 May 2010, the EU adopted the new Energy Performance of Buildings Directive 2010/31/EU (EPBD) which is the main legislative instrument in place to reduce the energy consumption of buildings. Under this Directive, MS must establish and apply minimum energy performance requirements for new and existing buildings, ensure the certification of building energy performance and require the regular inspection of boilers and air conditioning systems in buildings. The Directive requires MS to ensure that by 2021 all new buildings are so-called 'nearly zero-energy buildings'. However, a recent report by the Buildings Performance Institute Europe (BPIE) identifies the need for further guidance since weak rules put building efficiency off track [1]. The report says that EU countries may mismanage their energy efficiency commitments and risk missing their energy savings' target without further guidance. The report also said: *“The building sector is responsible for the largest share of energy consumption and greenhouse gas emissions and therefore they are a key sector to reach the long-term climate and energy targets".* The building sector accounts for 40% of the EU’s energy consumption and 36% of total CO_2 emissions. Therefore, building energy efficiency is key to achieving the reduction targets established by EU Policies.

Benchmarking is an important tool to promote energy efficiency in buildings and for influencing energy policy within building management [2]. Energy use in RCHE is becoming an important concern, because the population is aging at an increasing rate and because these centers operate 24 hours a day, 365 days a year, usually with full occupancy. Driven by falling fertility rates and increases in life expectancy, the elderly population will continue to increase. The findings of this study potentially have much broader applicability than the EU. The number of people aged 65 or older is projected to grow from an estimated 524 million in 2010 to nearly 1.5 billion in 2050, with most increase in developing countries [3]. In Europe, according to the European Association for Directors of RCHE (EDE), nearly 14% of the population is over 65 years old and 1.5 million people live in more than 24,000 RCHEs. Estimates indicate that in 2050 European elderly population will double, reaching about 60 million people [4]. The rising life expectancy within the older population increases the need for long term care services, since age also brings many health problems and disabilities (dementia, Alzheimer, several dependencies, etc.) which require specific care and continuous surveillance. The demand for professional care for elderly will inevitably increase because traditional living arrangements are changing: family size is getting smaller and the prevalence of co-residence by multiple generations is declining. The global trend toward having fewer children assures that there will be less potential care and support for older people from their families in the future [3]. Building experts and policy makers should definitely pay attention to the energy efficiency of this sector, since the increasing aging population will likely lead to an increase in energy use in this sector.

There have been many European projects regarding energy efficiency in buildings, namely REMODECE, ManagEnergy, Build Health, ASIEPI etc. Nevertheless, no one has dealt specifically with this particular niche of buildings. SAVE AGE is the first European project to restrict its scope to RCHE, having analyzed the current situation and sought out technical, behavioral, knowledge and financial obstacles and solutions towards energy efficiency. The development of benchmarks that enable the comparison of the energy performance of similar RCHE, across different countries, can have a large impact on the energy use within this sector.

Energy consumption benchmarks for office buildings have been already studied in several countries [5, 6, 7, 8, 9]. These benchmarks are based on statistical analysis, of data collected through forms and include all type of energy consumption used in the buildings.

Benchmarking in buildings has been established using several approaches, depending on the degree of detail of data collection and on how informative the benchmark should be. Sharp [10] used averages, medians, simple ranking and normalized ranking to benchmark commercial office buildings. The collection of a list of potential drivers for increasing the energy consumption of buildings and apply regression techniques to identify the statistically significant factors for normalization is also an usual practice [11]. Xuchao [9] concluded that ranking buildings based on their energy use intensity (EUI) provides a more informative benchmark. However, simple ranking can mask the results and can unfairly penalize some buildings (for example, hotels with high occupancy will be penalized compared to hotels with much lower occupancy). These factors that influence energy consumption, such as HDD, occupancy rate, number of employees, floor area, operation schedule, and building age, need to be normalized in order to make comparisons between buildings more equitable.

Our extensive literature search found that energy benchmarks have not yet been studied for RCHE. Moreover, RCHE lack knowledge and awareness on energy efficiency and they are generally quite reluctant to new technologies. Their main concern is to provide the best quality care they are able to, and they often neglect technical energy issues. The development of cross country comparisons of energy efficiency within RCHE will raise their awareness and drive decision making towards energy efficiency.

This paper presents the methodology to develop energy performance benchmarks for RCHE in order to compare the performance of similar institutions within the 10 European countries involved in the SAVE AGE[1] Project.

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[1] http://www.saveage.eu

In the first phase of the SAVE AGE project, an analysis of the total energy consumption in 100 RCHE (10 in each 10 countries) and building characteristics such as net area, year of construction, number of residents and employees, type of insulation, envelope materials, etc. was carried out. Energy consumption data and relevant information collected from the RCHE were subject to statistical analysis, and a multivariate regression based benchmarking model approach was established to correlate different EUI with factors that may influence the energy consumption of a building, namely heating degree days (X1), net area (X2), year of construction of the building (X3), number of residents (X4) and number of employees (X5) and year of retrofit (X6). This approach would allow comparing performances of different RCHEs, so that RCHE managers can assess European consumption levels and evaluate their own efficiency, acknowledging where they stand within a National and European sample. In order to compare the efficiency of RCHE, the following Energy Use Intensity (EUI) performance indicators were considered:

- EUI1 (kWh/m^2/year) – provides information on total consumption per square meter of the building;
- EUI2 (kWh/residents/year) – provides information on total consumption per residents;
- EUI3 ($kWh_{heating}$/m^2/year) – provides information on heating consumption per square meter;
- EUI4 ($kWh_{heating}$/residents/year) – provides information on heating consumption per residents.

Figure 1 summarizes the SAVE AGE benchmarking approach.

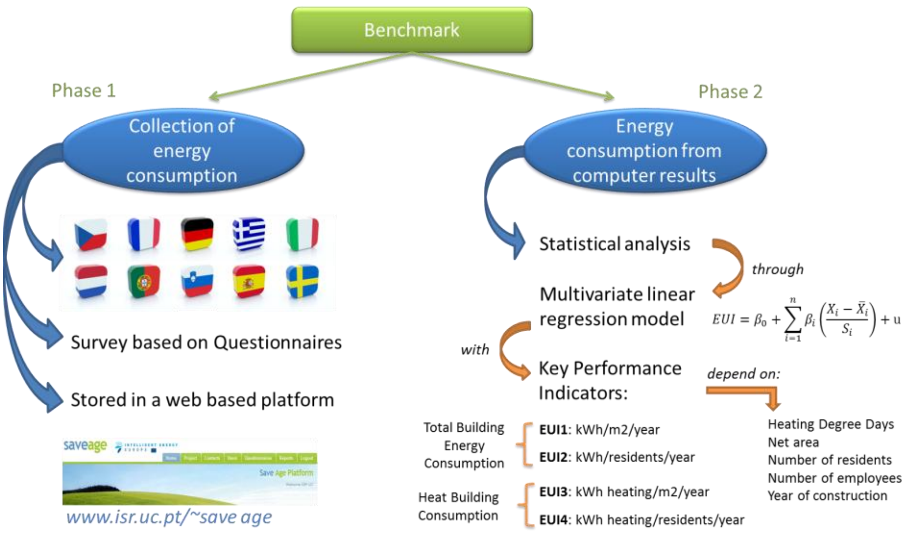

Figure 1 – Methodology of SAVE AGE Benchmarking

Methodology

To establish the energy efficiency benchmark, a literature survey assessment was carried out to collect information about energy efficiency benchmarks all over the world, in similar buildings. This survey enabled the collection of data related to performance indicators for assessing energy efficiency. In addition, a research on recent monitoring projects took place, in particular the Tertiary and REMODECE[2] projects, as well as older projects such as the SAVEII project DSM in Health-Care facilities, which aided decisions about on site data collection. Based on these assessments, it was possible to develop a detailed questionnaire used to monitor 10 RCHE in each of the 10 EU participating countries: Germany (DE), Greece (GR), Italy (IT), Portugal (PT), Slovenia (SI), Sweden

[2] http://www.eu.fhg.de/el-tertiary and http://remodece.isr.uc.pt

(SE), Spain (SP), France (FR), The Netherlands (NL) and the Czech Republic (CZ), hence a total of 100 RCHE.

The following phase of the project dealt with monitoring the RCHE. This monitoring was based on a detailed survey assessment which was based on the collection of the questionnaire filled in through interviews with the RCHE managers, technical staff, maintenance staff, nursery, etc. The advantage is that the energy consumption benchmark is more practical, because it uses statistical analysis of the data collected from the survey form. However, there is a limitation of this approach. As the benchmark relies on the number of RCHE of the sample, if the entire population is energy inefficient the result of the benchmark can be poor confident. Moreover, the only requirement imposed to the sample was to collect data from 10 RCHE in each country, located in different locations. Although no other requirement was considered in order to guarantee a statistically representative sample and assuming that the houses were randomly selected, the final set of 100 RCHE spread throughout Europe is believed to contain a representative sample of this type of facilities.

All collected questionnaires were stored in a specific database which was developed to store the huge amount of collected data in an effective way. A web based platform[3] enabled each partner to feed in the database with the information collected from the field surveys regarding general information of the RCHE such as number of residents, number of employees, number of rooms, etc.; construction details such as type of building, net area, type of terrain, etc.; heating/cooling; equipment; type of lighting; and building´s energy bills (electricity, natural gas, oil, etc.) for the three last years (whenever possible). In addition, climate factors have also been considered, since there are RCHE from countries with different climatic conditions and therefore climate adjustment of the energy data was considered in the analysis. Field collection of data is a huge task that is very time consuming, and it took longer than foreseen to collect enough data that could be useful to model the benchmark. This was a worthy effort, since data on energy supply and end-use are a pre-requisite for developing policies and initiating a change towards increased sustainability [11].

Climate factors

When applied to real-world buildings, common degree-day-based methods suffer from a number of problems that can easily lead to inaccurate, misleading results. Degree days should thus be handled with care and the most appropriate degree-day data should be used.[4] However, the degree-day data freely available is unlikely to be entirely appropriate for calculations relating to any specific buildings. Ideally, degree-day data should be obtained for an appropriate base temperature[5] and covering just the hours over which the building is heated. Heating degree days have been collected, but it was not possible to obtain degree-day data with an appropriate base temperature for all partners. However, it was possible to access mean-air-temperature data (e.g. monthly readings of mean air temperature), so the following methodology was used to obtain approximate degree-days, with a specified base temperature. The degree day value was defined as the difference between the daily mean temperature and the defined base temperature [11, 24].

Heating Degree-Days (HDD) are used for calculations relative to buildings' heating requirements. If considering a base temperature (T_baseH), and the daily average temperature T_out[i] for each day i in a period of N days[6], the HDD provides a measure of how many degrees and for how long the average outside air temperature was below the base temperature. Similarly, Cooling Degree-Days (CDD) are commonly used for calculations that relate the cooling of buildings - especially those using air conditioning. If considering a base temperature (T_baseC), and the daily average temperature

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[3] http://www.isr.uc.pt/~saveage

[4] http://www.energylens.com/articles/degree-days

[5] The base temperature is a reference temperature used to calculate the Degree Days and allowing comparing thermal performance among buildings located in different climates.

[6] Typically one year.

T_out[i] for each day i in a period of N days[6], the CDD provides a measure of how many degrees, and for how long the average outside air temperature was above the base temperature [23].[7]

Establishing the Energy Efficiency Benchmark for RCHE

Energy benchmarking is an assessment approach in which energy-related metrics measured or estimated at one building are compared to those from other buildings and/or specific performance targets. These metrics can be specified at the level of the building, a functional area within a building or specific systems and operations. Benchmarks can be derived from distributions of metric values obtained from buildings that have a similar functionality or characteristics. Consequently, improvements in benchmarking methods can have a large impact on the energy use within the building.

To compare the energy performance of the RCHE, benchmarking energy indicators have been developed. These indicators should enable the comparison of different RCHE as accurately as possible. This is accomplished by using indicators that are normalized, like EUI. The EUI is the average annual energy consumption normalized by net area of the building, and it is typically expressed in kWh/m^2/year.

This methodology of simple floor area normalized EUI was then developed using a multivariate linear-regression model approach to correlate EUI with factors that influence the energy consumption of the RCHE, namely HDD, number of residents, number of employees and year of construction. If the data is nonlinear, this approach may not fit very well the data and other more complex ways of data fitting might be necessary for a credible energy-consumption performance rating.

After the data collection, there is a need to treat and process this data in order to establish the energy consumption benchmarks in terms of the EUI.

The benchmarking model makes use of the “best-fitted” regression model to calculate the predicted EUI. The EUI can then be expressed based on a set of explanatory variables: X1…Xn. The linear multivariate regression is performed in Excel.

Performance Indicators

The performance indicators calculated for the benchmark are used as an energy performance rating system to compare different buildings with the same functional use.

Table 1 shows the Key Performance Indicators (KPIs) selected to be used to compare the performance of the RCHE. The following Energy Use Intensity performance indicators were considered: kWh/m2/yr, kWh/res/yr, $kWh_{heating}$/m2/yr and $kWh_{heating}$/res/yr.

Table 1 - Key Performance Indicators (KPIs)

Key Performance Indicator	Source of Energy	Units	Data Required	Comments
Energy Use Intensity (EUI1)	All sources (electricity, gas, oil, biomass, district heating, etc.).	kWh/m^2/yr	Annual energy consumption; Net area of the building	Provides information about the total energy consumption of the building per its net area.
EUI2	All sources (electricity, gas, oil, biomass, district	kWh/ residents/yr	Annual energy consumption; Number of	Provides information about the total energy consumption per

[7] Base temperatures assumption: 15ºC was established as the base temperature for degree-day-based calculations relating to the energy consumption of the heating system and 20ºC as the base temperature for degree-day based calculation related to the energy consumption of the cooling system [http://www.energylens.com].

	heating, etc.).		residents	resident.
EUI3	All sources of energy used for heating	kWh heating/m2/ yr	Heating energy consumption; net area of the building	Provides information about the heating consumption per square meters.
EUI4	All sources of energy used for heating	kWh heating/ residents/yr	Heating energy consumption; Number of residents	Provides information about the heating consumption per resident.

Selection of EUI and explanatory variables

The EUI (kWh/m^2/year and kWh/residents/year) are chosen as the dependent variables in the multiple regression models. Some factors that may affect the EUI, which were considered, are climate (degree days), number of residents, number of employees, age of the building and year of any retrofits. But there are other more qualitative factors which may also affect the EUI such as occupant's behavior, level of environmental awareness of user's, maintenance practices, etc. but these factors were not modeled since they are difficult to quantify or evaluate.

In the SAVE AGE study six explanatory variables, presented in Table 2, were considered in the multiple regression models.

Table 2: Explanatory variables considered in the model

Explanatory variable	Variable name
X1	HDD
X2	Net area (m2)
X3	Year of construction
X4	Number of residents
X5	Number of employees
X6	Year of retrofit

A random selected sample of 10 RCHE in each country was surveyed to develop a data-base for energy-efficiency benchmarking. In principle, a sample size of 100 is sufficient to provide a statistically significant model. However, due to the lack of important data for some countries and in some RCHE, there was the elimination of 8 samples, and the final number of houses considered in the analysis is 92 samples.

The multiple regression model

If we assume that the typical distribution of energy consumption is affected by the selected explanatory variables, including HDD, net area, year of construction, number of residents, number of employees and year of retrofit, (X1…X6), the multiple regression model for the EUI(kWh/m^2/yr) is given by:

$$EUI = \beta_0 + (\beta_1 * x_1) + ... + (\beta_8 * x_8) + u = \beta_0 + \sum_{i=1}^{8} \beta_i \left(\frac{x_i - \bar{x}_i}{S_i} \right) + u$$

Where x_i are the Xi explanatory variable average, Si is its variance, and β_i the regression coefficients that best fit a linear model to the available data and u represents the random error [6, 12]. The data analysis to obtain the above regression values has been carried out using Microsoft Excel. After modeling the data, an analysis of the influence of the explanatory variables in the indicators showed that the explanatory variable Year of retrofit does not have influence on the benchmark, and therefore was neglected. Therefore only the explanatory variables X1…X5 were considered in the final modeling of the data.

EUI1 (kWh/m^2/yr)

As an example, Table 3 summarizes the statistics of the survey results for EUI1. A similar procedure has been carried out for the other performance indicators EUI2, EUI3 and EUI4.[8]

Due to the presence of some outliers, the total number of houses considered in this case was 86. The Table presents the minimum and maximum values, the average and the standard deviation of EUI1 and the explanatory variables under evaluation. The linear coefficient generated by the model and the sensitivity of the model to a given variable (the product of the standard deviation of that variable by the linear coefficient generated by the model) is also presented in the Table 3.

Table 3: Summary of statistics of survey results of EUI1

	N	**Min**	**Max**	**Mean**	**SD**	**βi**	**Sensitivity to the model**
EUI1(kWh/m2/yr)	86	46	551	252	106		
X1 (HDD)	86	432	2775	1975	740	0,0329	24,35
X2 (Net area, m2)	86	220	18270	4278	2994	-0,0386	-115,84
X3 (Year of Construction)	86	1400	2010	1957	102	-0,0721	-7,32
X4 (Number of residents)	86	11	273	91	61	0,88732	54,43
X5 (Number of employees)	86	3	340	62	54	1,23484	66,12

As it can be seen the standard deviation is significant for all the explanatory variables. This is an indicator of large variability in the data sample.

R^2 is the coefficient of determination. It gives a normalized indication, ranging from 0 until 1, of the error from the model to the sampled data. If it is 1, there is a perfect correlation to the sample. Anyway, it is worth noting that with the heterogeneous data of the current sample, no model would provide a perfect fit. For the case of EUI1, R^2 is 0,4.

Figure 2 shows a frequency chart to depict the distribution of the RCHE according to their net area. This histogram is biased with most RCHE below 5,000 m^2, but the sample contains five outliers with areas above 15,000 m^2. The frequency of RCHE with more than 3,000 m^2 decrease as area increases. Houses with areas above 10,000 m^2 and with a relatively small number of residents were not properly modelled by the benchmark for the EUI1 (kWh/m^2/yr) indicator. This happened because the study includes only five houses above that area and the regression coefficient reduces too much the magnitude of the performance indicator that might result in unreasonable expected values, as happened with some cases in Germany, The Netherlands and Spain being treated as outliers.

[8] More information is available at www.saveage.eu.

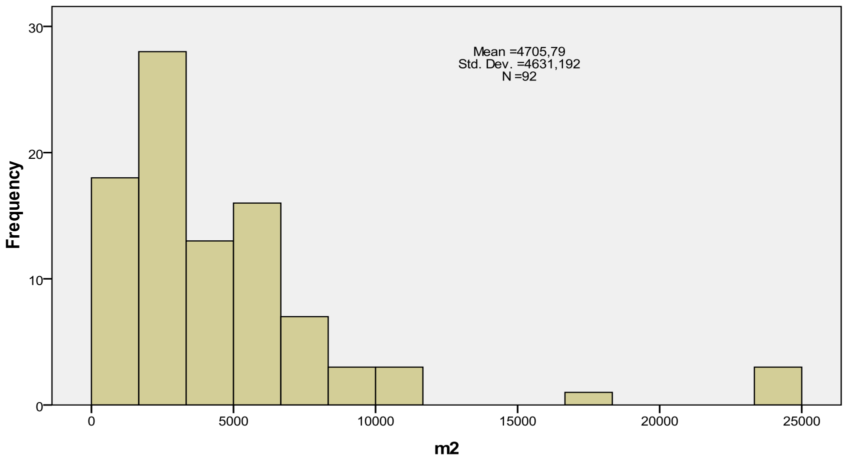

Figure 2: RCHE distribution according to the net area of the buildings

Major Findings

The multivariate linear-regression model originated, for each performance indicator, the following equations that correlate each variable with the benchmark value:

- EUI1 = 335,81 + 0,033.X1 - 0,039.X2 - 0,072.X3 + 0,887.X4 + 1,235.X5
- EUI2 = 5812,9 + 3,099.X1 + 1,107.X2 + 0,102.X3 - 76,222.X4 + 29,052.X5
- EUI3 = 224,31 + 0,025.X1 - 0,018.X2 - 0,068.X3 + 0,419.X4 + 0,429.X5
- EUI4 = 5531,2 + 1,818.X1 + 0,549.X2 - 1,285.X3 - 34,800.X4 + 5,327.X5

In Figures 3, 4, 5 and 6, the indicator EUI1 is plotted against net area, number of residents, number of employees and HDD, respectively. Real values are presented in different colours for each country. Benchmark trend lines are also plotted.

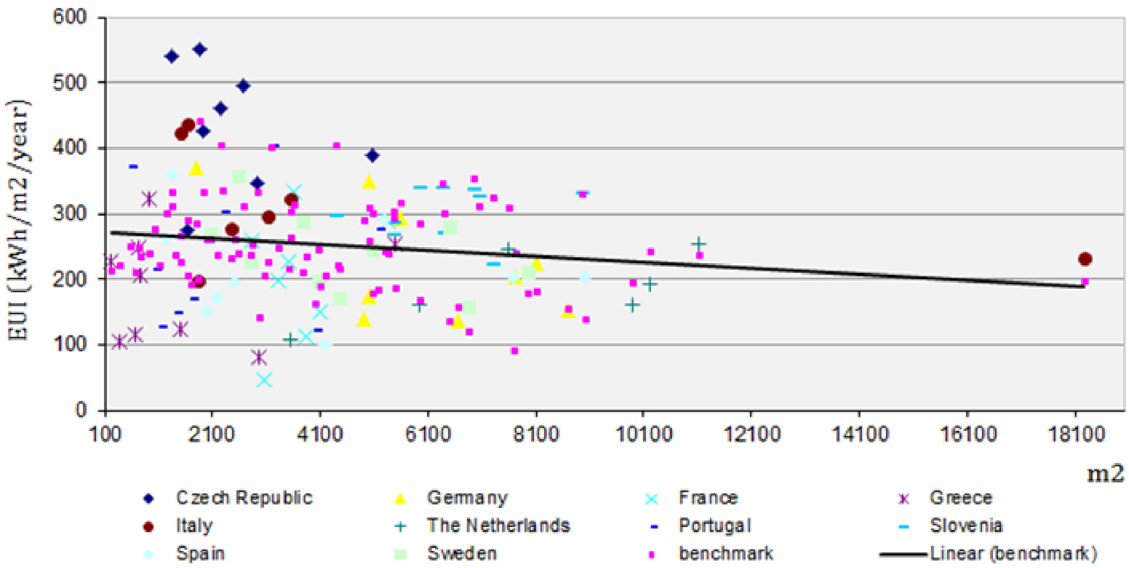

Figure 3. EUI1 (kWh/m^2/yr) versus net area (m^2)

As expected, the energy consumption per square meter decreases as the net area of the building increases. This does not mean that larger buildings perform better; it just means that a building consumption increases less per square meter as the net area increases.

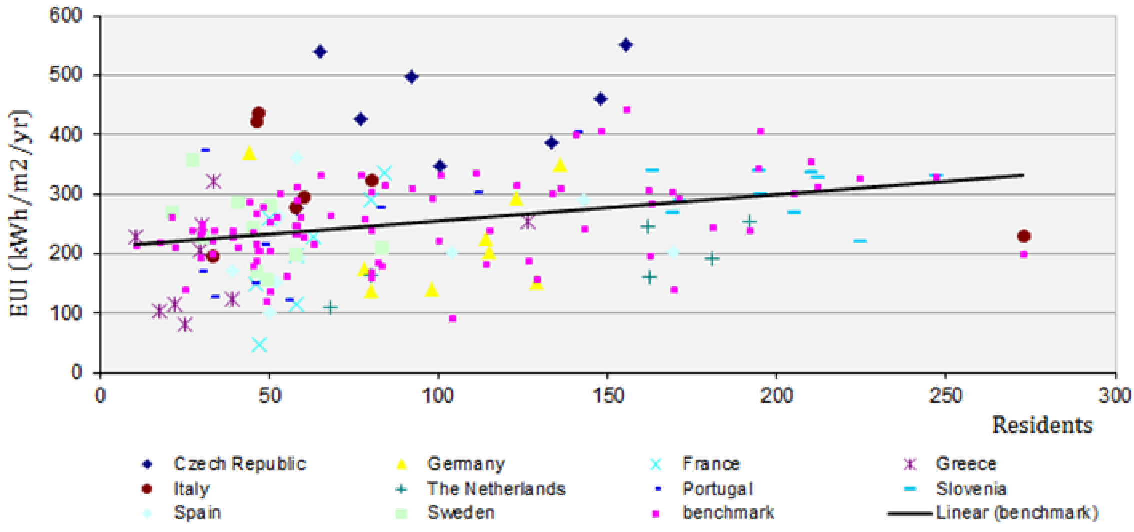

Figure 4. EUI1 (kWh/m^2/yr) versus number of residents

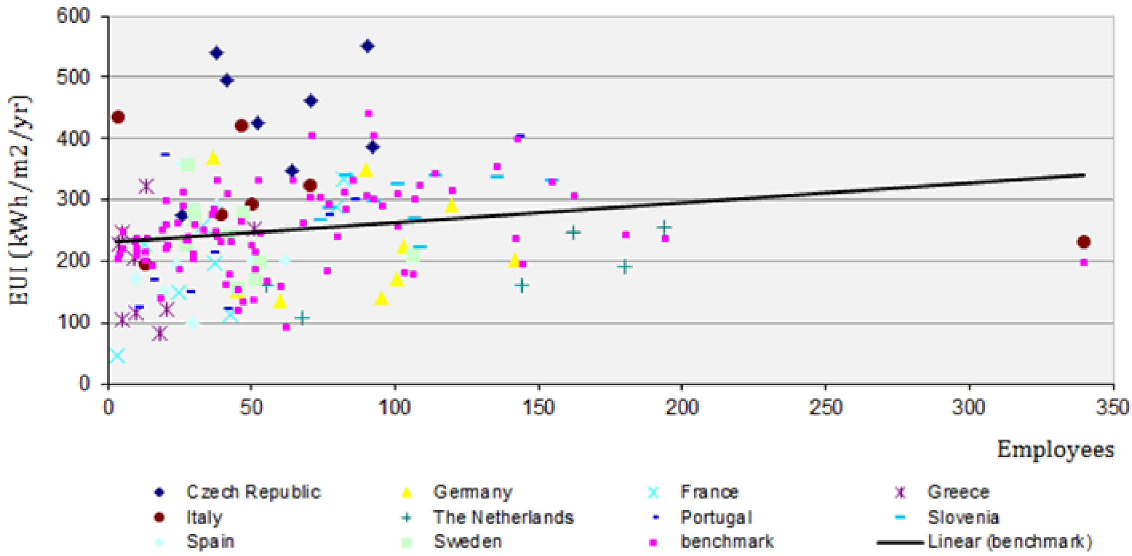

Figure 5. EUI1 (kWh/m^2/yr) versus number of employees

As it can be seen in Figures 4 and 5, there is a positive correlation between the energy consumption per square meter and both the number of residents and the number of employees. However, this relation is not very strong as the slope of the trend line is low in both cases.

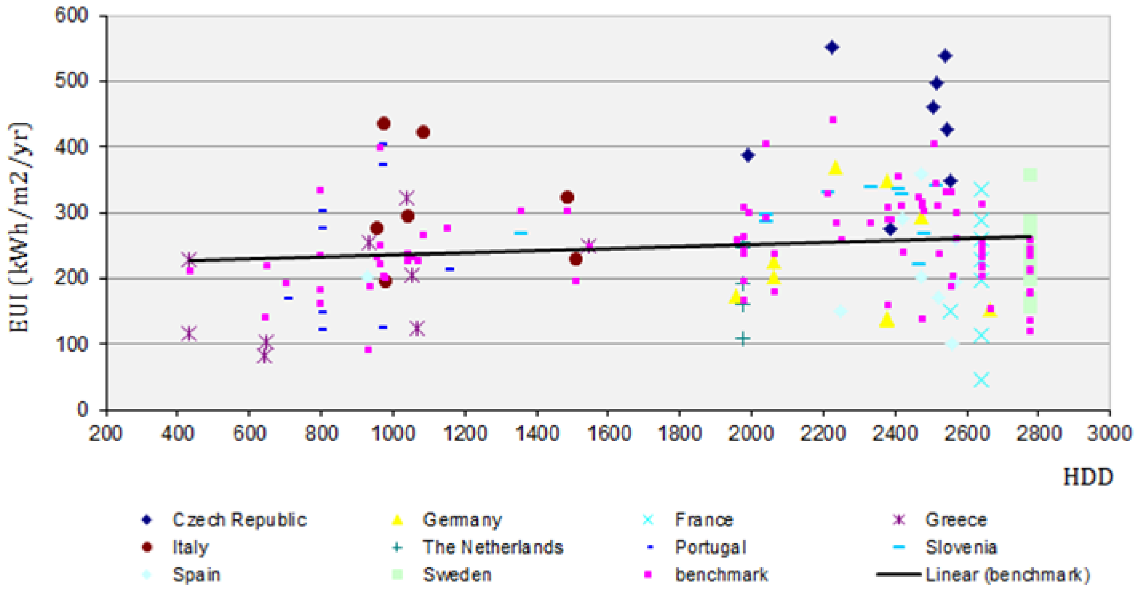

Figure 6. EUI1 (kWh/m²/yr) versus HDD

There is a very small positive correlation between HDD and energy consumption per square meter. There are two main range levels of HDD: small number of HDD: [500; 1500], and large number of HDD [2000; 3000]. It is also possible to conclude that some RCHE are performing better than others for the same order of magnitude of HDD, both within the same country and across different countries.

Figures 7 and 8 plot the EUI2, energy consumption per resident per year and the EUI4, energy consumption used for heating purposes per resident per year, respectively, against the HDD. Both indicators have a positive correlation with HDD. Due to space limitation, this paper does not present all the graphs for the four Indicators, which can be found at the project web-site. The decision was to include here the indicators presenting stronger correlation with the explanatory variables.

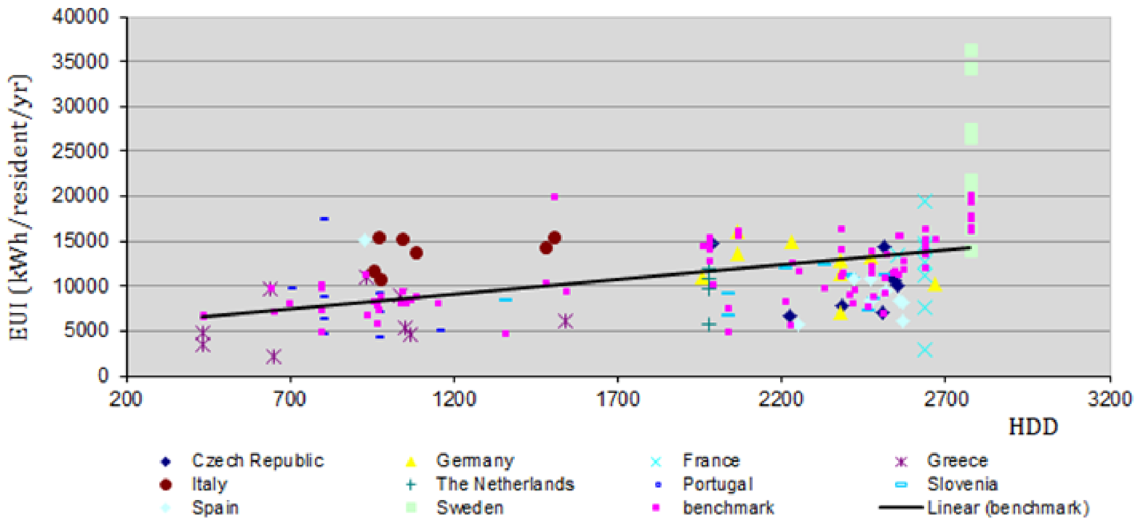

Figure 7. EUI2 (kWh/resident/yr) versus HDD

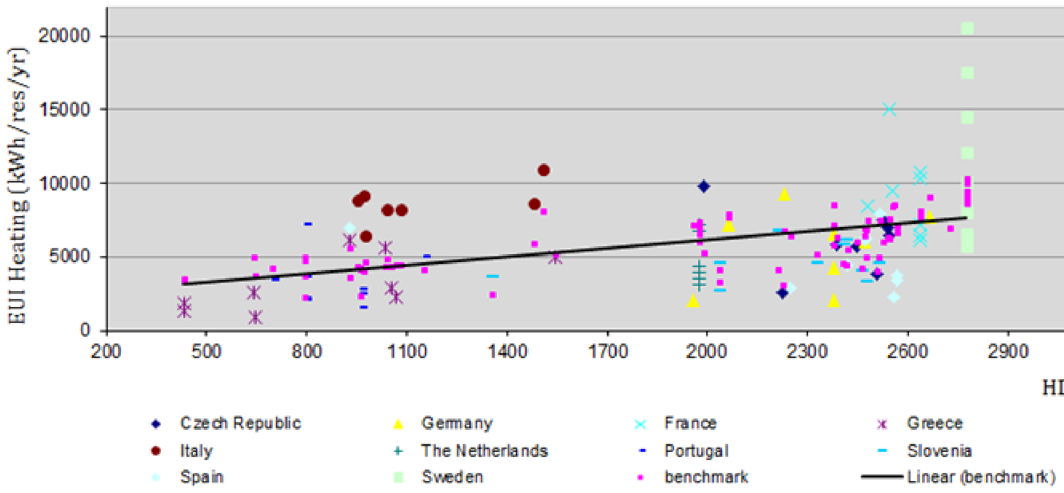

Figure 8. EUI4 (kWh/resident/yr) versus HDD

In the same country, with the same HDD, it is possible to find RCHE with very different heating consumptions per resident per year. This is particularly significant for Sweden and France but is also true in other countries like Italy, Greece and Germany.

Conclusions

If we look at the differences between the benchmark value for the different performance indicators and the real consumption value, as can be seen in Table 4, the following conclusions can be drawn:

Table 4: Real and estimated average values for indicators EUI1-4

	EUI1		EUI2		EUI3		EUI4	
	kWh/m^2/yr		kWh/residents/yr		kWhheating/m^2/yr		kWhheating/residents/yr	
	Estimated	Real	Estimated	Real	Estimated	Real	Estimated	Real
CZ	344	435	10012	10311	177	247	5429	6077
DE	244	227	14463	12275	128	110	7452	5812
FR	236	186	14468	10983	125	121	7751	8386
GR	214	187	7984	6241	106	101	4173	3159
IT	234	312	10498	13855	113	193	5195	8633
NL	237	187	14204	10744	112	82	6810	4824
PT	252	236	7857	8008	119	79	3868	3338
SI	326	301	7887	9741	162	141	4245	4599
SP	228	215	12266	9229	127	118	6728	4866
SE	203	241	17618	24521	117	110	9251	11133

EUI1: The average value for EUI1 is 252 kWh/m^2/yr. Within the sample, it varies from 46 kWh/m^2/yr in one RCHE in France to 551 kWh/m2/yr in one house in Czech Republic. Czech Republic, Italy and Sweden are the countries where RCHE are using more energy than the model estimated.

EUI2 ranges from 2215 kWh per resident per year in one house in Greece to the huge amount of 36349 kWh/residents/yr in one house in Sweden. Within a given country, the energy consumption per resident per year can vary significantly. According to the model, the maximum value should be 20156 kWh/residents/yr. Czech Republic, Italy, Portugal, Slovenia and Sweden are the worst countries in terms of total energy consumption per resident.

EUI3, which represents the heating consumption per square meter per year, is estimated to be 129 kWh/m2/yr, however the maximum reaches 333 kWh/m2/yr in one RCHE in Czech Republic, while the model predicts 216 kWh/m2/yr. Czech Republic and Italy are the worst positioned countries in terms of this heating indicator.

EUI4: The heating consumption per resident per year, as with EUI2, reached a maximum value for one particular house in Sweden, with 20556 kWh/residents/yr, while the model expected value for that situation is 10351 kWh/residents/yr. The average heating consumption value per resident per year is 6109 kWh. The countries with the highest heating consumption per resident are Czech Republic, France, Italy, Slovenia and Sweden.

Lessons learned

There is a large heterogeneity in the collected data, reflected by the sparse point clouds in the figures 3-8. Additionally, no non-linear tendency can be observed. Therefore, in an attempt to establish benchmarks in the 10 countries, multivariate linear regressions were fitted to the collected data, in order to model the energy consumption. Considering such sparse data, large global deviations between the models and the data were obtained, reflected by relatively small values of R^2.

Considering the sensitivity of the model to a given variable as the product of the standard deviation of that variable with the linear coefficient obtained by multi-linear regression, we can conclude that the most relevant variable for EUI1 and EUI3 is the net area and for EUI2 and EUI4 is the number of residents.

Since some outliers were found, it is advisable to double-check the information relative to those houses and eventually to carry out complementary data able to fill in the gap in-between the normal data and the outliers. As it is the basic idea of descriptive statistics, when encountering an outlier, we have to go further on the analysis and find out its cause. Insignificant explanatory variables should also be eliminated.

Acknowledgements

The SAVE AGE project was mainly supported by the European Commission, Executive Agency for Competitiveness and Innovation (EACI).

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Whole Home Energy Use Study with Comprehensive Metering Package

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Ecotope, Inc.

Abstract:

The Pacific Northwest of the United States relies on a regional energy plan which is updated every 5 years. The first plan was published in 1981 and each plan prioritizes acquisition of conservation and renewable energy sources. The next plan will be published in 2014, and a comprehensive Residential Building Stock Assessment (RBSA), began in 2011 to provide a statistically representative summary of residential building characteristics throughout the Pacific Northwest. This study involved a half-day field audit of approximately 1400 site-built and manufactured homes. A subset of these homes received more detailed audits that focused on heating/cooling distribution efficiency and house air-tightness.

The Whole Home Energy Use Study (WHEUS) is part of the RBSA and directly measures most energy uses (natural gas/electric heating, cooling, hot water, 240 volt AC (VAC) appliances), plug loads, major 120 VAC appliances, and lighting in a sample of 100 homes which are statistically linked to the RBSA sample of 1400 homes. Data are collected as 5 minute summaries and include both energy and power (and duty cycle for lighting) plus additional measurements.

This paper will focus on two elements of the WHEUS. First, it will describe the design of the metering plan, focusing on how three different data logging platforms were designed and then melded to provide nearly real-time usage data. The semi-automated error-checking that is key to ensuring data quality will be described. Second, the paper will present some of the preliminary results, including whole-house and appliance-specific usage and time of use profiles.

1. Background

Recent history of the Pacific Northwest, especially that involving electricity production and distribution, has centered on the network of federally-financed dams that are operated on the Columbia River and its tributaries by the Bonneville Power Administration. Hydroelectric power has provided almost all of the electricity for the region until very recently and regional planning has therefore largely been the province of BPA (with a limited number of natural gas and coal-fired plants, plus some nuclear energy making up the difference). Wind power generating capacity has increased rapidly in the last decade and now represents a potential resource equal to about half of the average regional demand of about 9000 MW.

In the late 1970s, projected rapid growth of electricity demand led BPA to underwrite construction of a five facility nuclear power network. Demand did not materialize as expected, the bonds that had been sold to finance the project went into default, and BPA was compelled by federal legislation to agree to a broader regional planning process overseen by a new agency, the Northwest Power Planning Council (now called the Northwest Power and Conservation Council). The Council would prepare a regional plan every five years (prioritizing conservation and renewable resources) that

BPA and its customer utilities (over 150 in all throughout the region) would use as a blueprint to acquire conservation resources. These resources would come from a combination of utility programs and changing energy codes (which are administered by the four states in the region: Idaho, Montana, Oregon, and Washington). Periodic evaluations by the Council and others have concluded that conservation programs have succeeded in delivering an accumulated 500 MWa[1] over the past thirty years [1]. This is an impressive accomplishment, especially in a region where electricity's average cost is typically under $0.10 USD/kWh. Note this graphic shows conservation gleaned from all sectors (residential, commercial, and industrial), with residential conservation estimated to have saved about 50% of the total over the past 10 years [2].

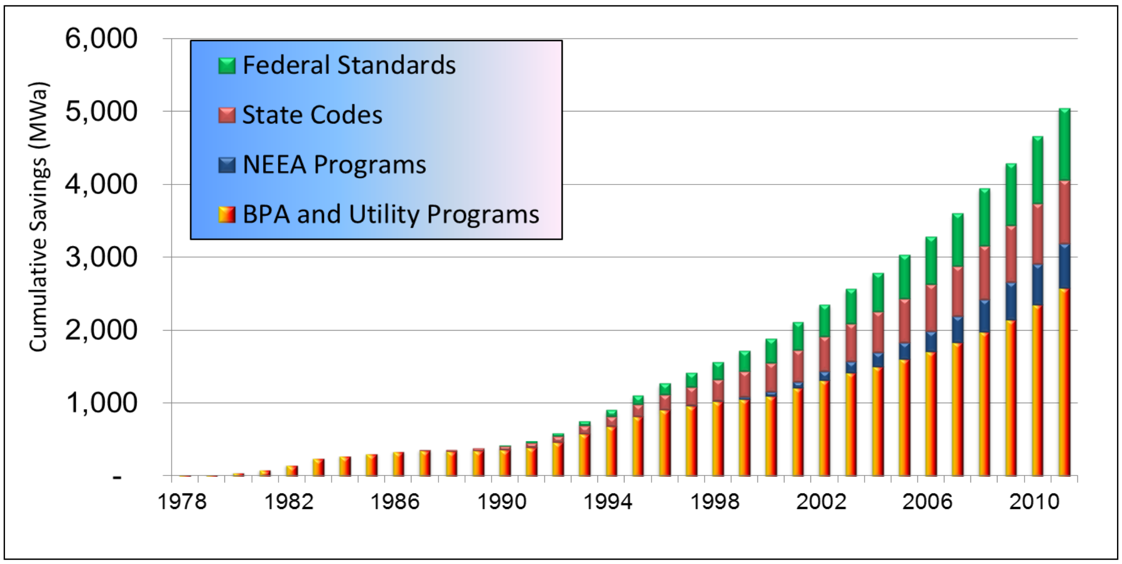

Figure 1. Historic Conservation Acquisition in United States' Pacific Northwest

The region's last major regional end use study, the End Use and Consumer Assessment Program (ELCAP) was begun in the mid-1980s, with most analysis complete by the early 1990s [3]. This was a $60 million study (1988 USD), with the bulk of its effort concentrated on commercial/industrial end uses. Still, about 400 homes were instrumented in some form (but no plug load or lighting data were collected due to limitations in metering technology). The energy use and load shape data from that study has been used by the Council and others in several regional Plans. A few additional, smaller-scale end use studies have been conducted since ELCAP but the region has badly needed an update.

The seventh regional Plan is now in preparation. A key element of the Plan is analysis of data that is now being provided by the Residential Building Stock Assessment (RBSA). This study, funded by the Northwest Energy Efficiency Alliance (NEEA) is a general survey-based study that provides a statistically representative summary of residential energy use characteristics throughout the region [4]. A subset of about 10% of the 1100 single-family homes in this study are the subject of intensive end-use metering (the Whole Home Energy Use Study (WHEUS)) and that is the subject

[1] An average megawatt is the amount of electricity produced by the continuous production of one megawatt over a period of one year.

of this paper. Results from both studies support the Council in preparation of the 7th Plan, support the region's utility conservation programs, and also may provide a test bed for new technologies of interest to the region.

There are 101 single-family sites in the study, drawn from five regions across the Northwest. The distribution is approximately population-weighted. The sample was designed to focus the sampling resources on areas with large populations (that is, clustered around the major population centers, which are typically less than 100 miles from the Pacific Ocean and therefore in a relatively mild, maritime climate) as well as areas with diverse climates. The two most populous areas (Puget Sound and western Oregon) were sampled separately; about one-third of the sample was drawn from three eastern regions, including eastern Washington, Idaho, and western Montana.

Whereas there are adequate west-side sites to ensure statistical robustness, various recruiting challenges on the east side prevented drawing of a statistically significant sample by sub-region. The minimum statistical criteria were set at 80/20. These criteria allow substantial variation while still allowing some variables to be reported that will have a wide confidence interval. Setting these criteria as a minimum ensures that most data points could be useful in establishing a generalized picture of the region's residential customer energy use. For the individual sampling areas, the coefficient of variation (CV) was set at 0.85, which means that the ratio between the mean and the standard deviation of any one metered result could be as high as 85% and still meet the minimum statistical criteria. Nevertheless, results from the east side can be viewed as broadly representative of the energy usage of the region's more continental climate (which has from 30-80% more heating degree days than the west and which also typically has more demand for mechanical cooling (even though cooling represents on average less than 20% of the house's HVAC usage).

2. Metering Plan Elements

In concert with the regions' keen interest in careful energy planning, this project had to construct a durable metering plan which would be adaptable to a range of housing sizes and energy use loads. The plan would have to be able to measure as many individual loads in the house as possible (both at the electrical panel and elsewhere), be secure, and allow for remote monitoring and retrieval of data. Sites would be spread out over several thousand square miles over a period of at least 2 years, so there would have to also be careful consideration of cellular communication service.

The final metering plan included 3 parallel platforms. The first was centered at the house electrical panel and includes direct measurement of the whole house service drop plus major 240 VAC appliances such as heating systems, water heaters, and laundry equipment. The second platform is based on a network of branch circuit measurement nodes to pick up items such as consumer electronics; this platform included both wired and wireless elements. Finally, lighting fixture on-time is measured with stand-alone data loggers. This platform is the only one that requires on-site visits to gather data.

The metering platform in this study is not limited to measurement of electrical loads but also tracks consumption of gas-fired appliances (with a focus on gas furnaces and water heaters). Very little detailed information has been available in the region on residential natural gas load shapes, especially in relation to a physical survey of the home and related usage influences, and therefore this work will improve understanding of the major end uses in natural gas homes. Measuring gas usage can be challenging [5] but the approaches used in this study (current-sensing relays and thermocouples) have allowed a reasonable, safe estimation of time of use and accumulated consumption.

The combined platforms collect nearly 600,000 data points per day across the three platforms. Most of these data can be checked nightly using automated routines (described in following sections) but the lighting data is picked up manually (since those data loggers do not permit remote access).

2.1. End Use Measurement Architecture

Data from most end uses are uploaded to Ecotope's servers once per day. These data include the heating, hot water, appliances, and plug loads. The exception is lighting loggers, which are not networked and are periodically downloaded manually.

There are multiple layers of security at every level of the system so that data and participant privacy are protected. Within the home, the dataloggers, networking equipment, and wireless networks are all locked down to prevent access. The network between the homes and Ecotope is a private network, so unauthorized access is not available from the public Internet. In addition, there are firewalls both at the entrance to the home and at the gateway to Ecotope's servers. The network runs over a virtual private network (VPN) to enhance security further.

Site, datalogger, and sensor status is monitored continuously, primarily for network latency and uptime. Data streams are automatically checked for a variety of issues including unusual gaps and out-of-range values. Problem reports are generated automatically and reviewed by program staff. This monitoring system enables Ecotope to quickly address issues with equipment that may have broken or been moved by participants.

Many network issues can be handled remotely. The custom datalogger also acts as a management platform with tools that allow other networking equipment to be updated and fixed remotely. The ability to perform these tasks remotely delivers better overall uptime and reduces the number of site visits.

Redundancy is built into the system in a number of ways. The dataloggers store log files locally in addition to transmitting them to Ecotope's servers. If an issue arises with a file on the server end, the original can be manually retrieved. The two VPN servers that run the network both have the capacity to support the entire network on their own, so if one fails the network will not go down. The 3G router within the home can perform as a backup wireless router if the primary router fails.

The entry to the home is a 3G cellular router. The 3G router is connected to two dataloggers and a wireless router. One datalogger is an off-the-shelf product that manages the heating, domestic hot water (when heated with electricity), and any appliance that has a dedicated circuit at the electrical panel. Ecotope developed a parallel datalogger platform to support the plug load meters and provide a network management platform in the home. The wireless router runs the plug load network, directing traffic to the custom datalogger. Plug load meters communicate with the router via small wireless nodes. Figure 2 shows this network.

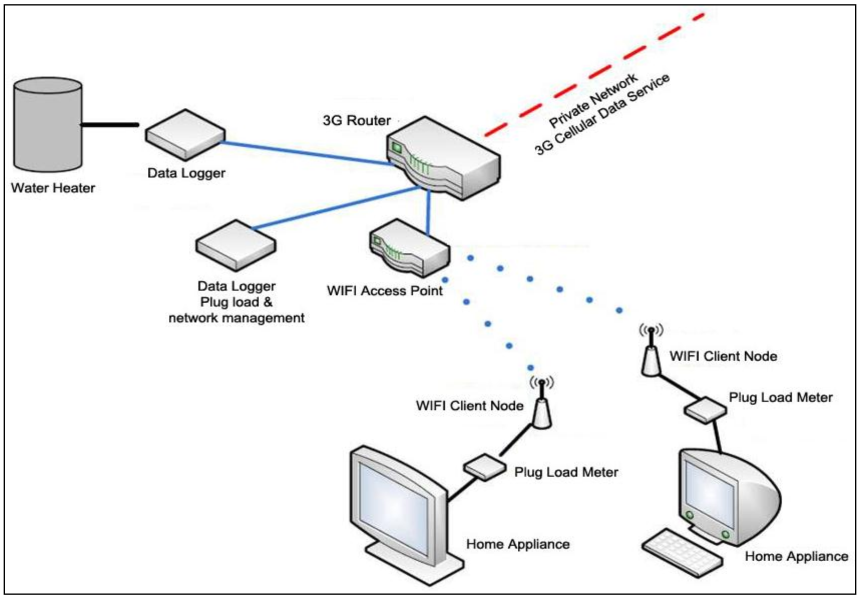

Figure 2. WHEUS Data Collection/Transfer

The 3G routers connect via a private cellular data network to redundant VPN routers at Ecotope. Traffic is routed through a firewall before reaching Ecotope's servers. Because the network is a cellular data network and not a phone network, connections are always live; this factor allows active monitoring of equipment, which helps ensure data quality. Finally, as mentioned above, the network is private, with no access to the public Internet.

2.2. Data Warehousing and Quality Control

The flowchart in Figure 3 depicts how data flow from raw sensor data and site visit forms to deliverable analysis materials. The process starts with physical sensors in the field, which send raw data in comma-separated value (CSV) log files to Ecotope's servers. From there the data are vetted, accumulated, rearranged, and eventually collapsed into high-level summaries and charts. Exploratory data analysis software and custom scripting routines are essential to this work. Very little data storage, cleaning, or analysis are done outside of these platforms.

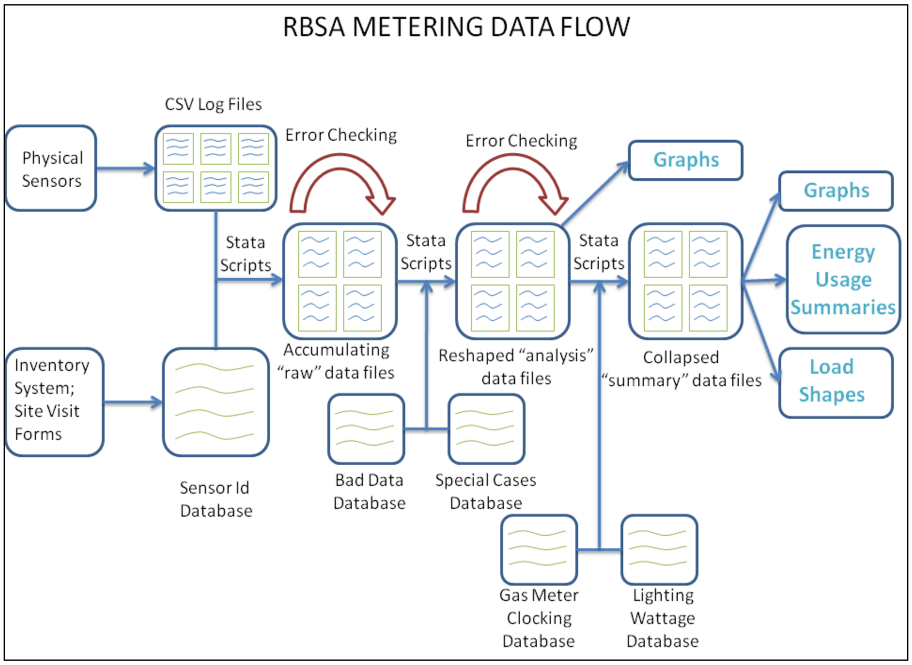

Figure 3. WHEUS Data Flow & Processing

New data are uploaded to Ecotope's servers, and aggregation code runs once daily to incorporate the most recent data. The nightly processing code performs aggregation and error checking according to two general steps.

In the first step, new log files are opened, examined, and parceled accordingly into accumulating datasets, grouped by site ID and sensor type. Stray files and files lacking usable records are discarded. Data gaps, readings in violation of preset, credible bounds, and missing or stale sensors are recorded in a nightly error report.

In the second step, accumulating files for each site are merged together into a single analysis file of five-minute raw data, with known bad data removed and special cases computed. These files are referred to as the reshaped analysis files. Residual errors (i.e., instances where the sum of metered end uses exceeds the measured service load) are tabulated and recorded in the nightly error report, along with a summary of the data fraction acquired and service fraction metered. The reshaped analysis files store the data in physically meaningful categories such as temperature, power, and time. Graphing routines referencing these files help analysts visualize the incoming data. These graphing routines prove valuable in investigating problems flagged by the error reports.

Examining each piece of raw five-minute data, even visually, quickly becomes overwhelming. Broader trends are investigated with a third analysis step, which involves collapsing the reshaped files into hourly, daily, weekly, monthly, and yearly summaries. In addition to aggregating by a coarser unit of time, all measurements of ontime from the reshaped files are converted into energy, which includes lighting and gas devices. Lighting wattages and gas appliance energy input rates are merged with the reshaped files before time aggregation. The broader time scales of the collapsed summary files assist in summarizing energy use patterns and creating end-use load shapes.

An exception to the automated file uploads and near real-time data collection are the lighting loggers, which do not upload data automatically. Each lighting logger data download includes time synchronization, to ensure that the loggers are correctly recording time, which is the basis of alignment with other data. After each download, aggregation code accumulates, reshapes, and collapses the most recent lighting data in a manner virtually identical to the continuously updating data.

The specific errors encountered are summarized and then sent to project staff in nightly reports (spreadsheet format). Gaps in the data and non-responsive sensors may indicate hardware failure, a weak wireless signal, or the fact that a participant moved or unplugged a sensor. Range checks, in which recorded values are examined against credible bounds, often indicate a malfunctioning sensor or a post-processing multiplier that must be applied or adjusted. For instance, we never expect outside air temperature to be colder than -50°F or warmer than 120°F. Power measurements should never drop below zero. Likewise, extreme energy usage data (for example, a gaming system recorded as drawing 4 kilowatts (kW) of electricity) also indicates a measurement error. Errors of this sort are bundled into the nightly report. These range checks are performed with a power "snapshot," rather than average power over the five-minute logging interval, and sometimes deliver false positives in the case of devices with motors, capturing inrush current at startup. Range violation requirements have been relaxed accordingly for devices such as gas furnace air handlers, in which we expect periodically high inrush currents. Residual violations, where the metered end-use power draws add up to a value greater than the whole-house service power draw, also indicate malfunctioning sensors or incorrect post-processing multipliers.

In addition to the automated error checking, Ecotope also performs quality control spot checks. This step involves analysts examining selected sites and sensors at random intervals. Typically, the analyst visualizes the data through various graphing routines to see if the data spin a believable narrative. For example, television usage that peaks at 1:00 p.m. and is virtually zero at 9:00 p.m. would bear further investigation. It might be an accurate pattern if the house is occupied during the day, but it does not fit with "prime-time" viewing habits. Therefore, it might indicate a time synchronization error. This approach is very time intensive so is only used sparingly, but it can sometimes find issues missed by the automated error routines or lead to the development of additional automated routines. Next, analysts also visually inspect site data after the automated error checks alert them to potential problems. Data plots allow the analyst to home in on the error and direct field staff to the specific problem, which can then be targeted in a site repair visit.

The cost of this extensive data checking totals to about 25% of the total 2 year budget of about $2.9 million. Ecotope's current estimate of believable data harvested is very high, though- about 87% of all possible data. This rate of successful capture is key to the success of the regional energy planning process.

3. Site Case Studies

The first case study is for a house (Site 22938) in East Wenatchee, Washington, with all electric loads including a tank water heater, forced-air furnace, and central air conditioner.

Figure 4 displays the most basic monitoring data output – the five-minute average power consumption by major end use. All of the loads plotted stack together to produce the total metered load. The whole-house service load drawn in black is metered separately. Whenever there is white space between the top of the colored plot and the black line, there is some load in the house that is not being separately metered (in this example, lighting is not plotted, which likely accounts for most of the white space).

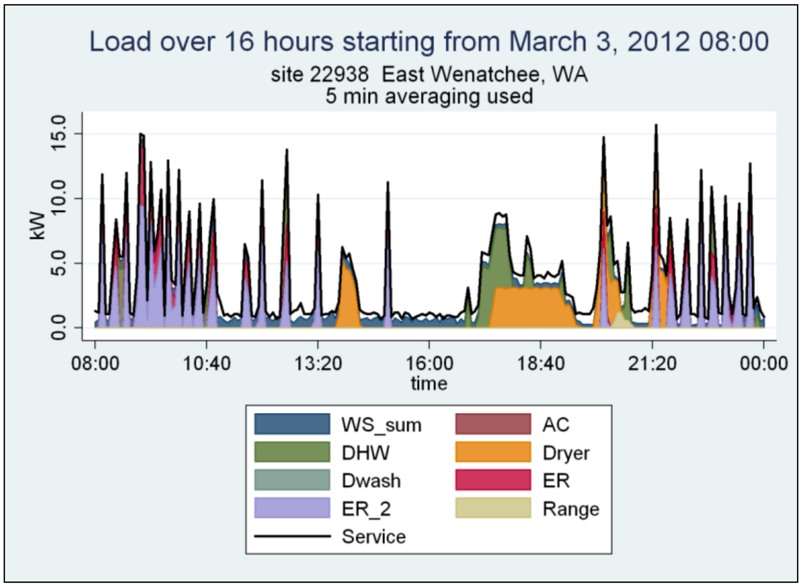

Figure 4. Five-Minute Summary Loads at Site 22938

The furnace has two stages of electric resistance (ER and ER_2). The heating elements engage simultaneously upon a call for heat and account for the largest loads during the day. Note that furnace runtime is greater in the morning than in the afternoon. The next two large loads are the water heater (DHW) and clothes dryer (Dryer). The electric tank water heater shows typical standby recoveries throughout the day and then a major water heating event starting at about 5:00 p.m. On this Saturday, the occupants used the electric dryer four times. At around 8:00 p.m., the kitchen range (Range) was used. The sum of all monitored plug loads is plotted in dark blue (WS_sum).

Using the same time period as Figure 4, Figure 5 plots many plug-in devices that are connected to standard 120-volt branch circuits. On this graph, the plots do not stack but rather show the power consumed by each device.

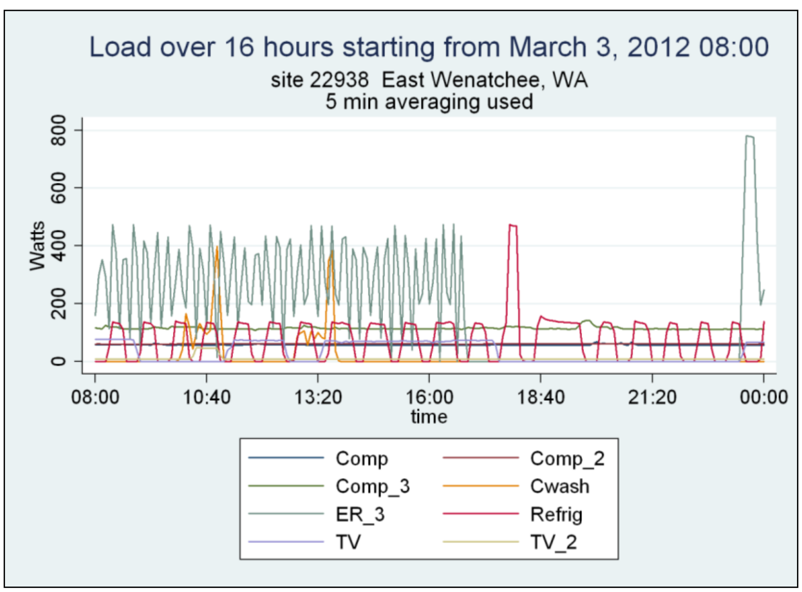

Figure 5. Monitored 120V Plug Loads at Site 22938

During installation of the metering equipment, the occupants indicated that they used a plug-in electric space heater to augment the central furnace heat output. That space heater (ER_3) shows regular use in Figure 5. The figure also shows a typical refrigerator (Refrig) usage pattern. The refrigerator compressor cycles on and off with roughly a 45-minute period to maintain the main box setpoint. Near 6:00 p.m., there is a spike in refrigerator usage, suggesting an automatic defrost event. Two clothes washing cycles (Cwash) occurred between 10:00 a.m. and 2:00 p.m., which correspond with the four dryer cycles noted in Figure 4.

The computers and televisions show more constant loads. The five electronic plug loads plotted in Figure 6 represent three computers (Comp, Comp_2, and Comp_3) and two televisions (TV and TV_2). The plots show that the computers are constantly left on throughout the day. Comp and Comp_2 draw a constant 60 watts (W), and Comp_3 uses about 120 W. One of the televisions (TV) is used for much of the day and draws 80 W when on and nearly 0 W when off. The other television (TV_2) is used for about 30 minutes from 10:30 to 11:00 a.m. TV_2 draws less power than TV when on, but has a standby consumption of nearly 10 W.

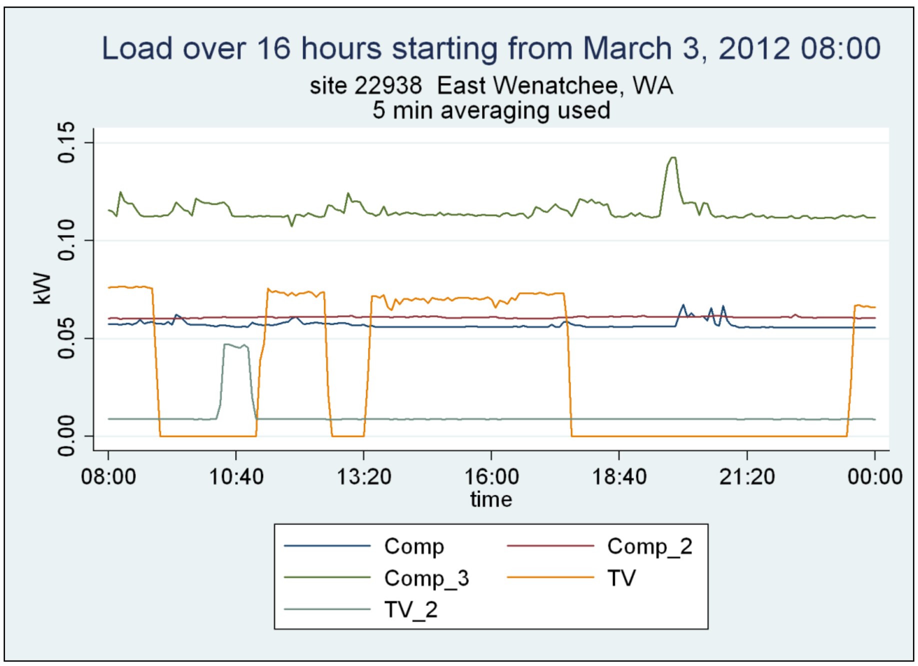

Figure 6. Televisions and Computers at Site 22938

3.1. Consolidated Data

The high-resolution plots of energy use over hours and days facilitate specific and immediate investigations into individual channels and house behavior. Looking at many of these plots at a time, however, quickly becomes overwhelming. Broader patterns are visualized with a set of tools that accompany the collapsed, summary datasets, in which usage can be investigated at hourly, daily, monthly, or yearly intervals.

For example, Figure 7 shows data collapsed by day into end use category. The figure gives an overall picture of energy use for a house (Site 11418) in Carlton, Oregon. The house employs an air source heat pump for space conditioning and an electric resistance tank for water heating. It shows relatively constant DHW and appliance usage. The HVAC usage responds as expected to decreasing outdoor temperatures (ODT). The blue area at the top of the bars shows the remaining house service load not captured by the meters.

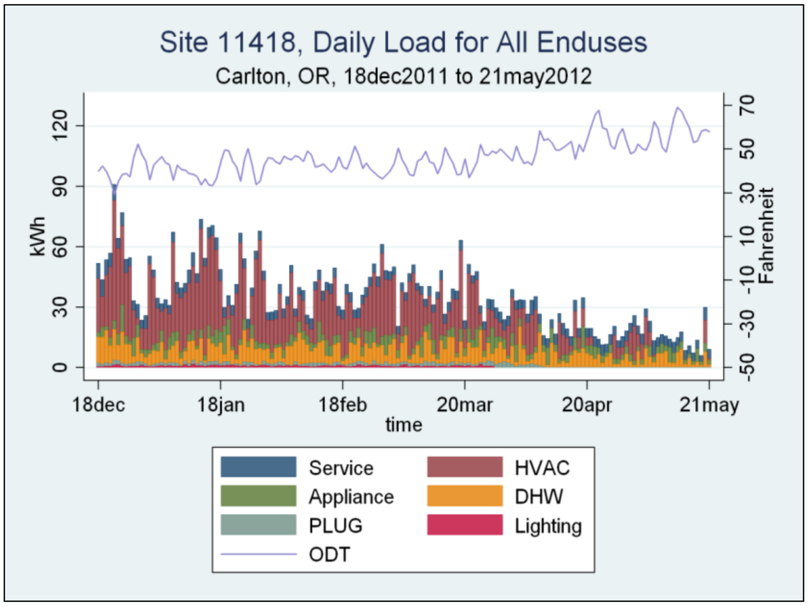

Figure 7. Daily Load by End Use at Site 11418 **(ODT = outdoor temperature, DHW = domestic hot water)**

Table 1 presents the same type of data that are used to produce graphs like Figure xx and consolidates the daily energy use for each major load category. For example, some of the data from the first winter's monitoring at Site 22938 include the coldest times of the year; the electricity usage in the house is dominated by the electric resistance heating. Note the lower number of days for lighting data; the most recent visit to retrieve lighting data was in early March, providing 122 days of data. Table 2hows that approximately 90% of the whole house service load was metered. Some of the "missing" 10% of the total service entry consumption can be attributed to lighting data yet to be collected, and the rest can be attributed to the occupants using devices not metered by our system.

Table 1. Consolidated End Use Data for Electric Resistance Heat Site 22938

Site 22938	# of days	kWh/day				% of Service Load
End Use		Mean	SD	Min	Max	
HVAC	216	56.7	38.6	0.0	145.0	69%
DHW	216	8.2	3.6	0.0	18.2	10%
Appliances (non-DHW)	216	3.4	3.4	0.0	16.2	4%
Plugs	216	5.1	1.3	0.0	6.8	6%
Lights[2]	122	0.7	0.7	0.0	3.0	1%
Total Submetered	216	74.1	40.6	0.0	161.9	90%
Whole House Service	216	82.6	41.3	0.6	173.2	100%

[2] Lighting data only for 122 days due to manual downloading. This biases the lighting fraction low in the table.

Another set of summarized end uses is presented in Table 2 for site 11418 in Carlton, Oregon. The data in the table cover 173 days from January to June 2012. Like the data from the Wenatchee site, this time period covers the cold heating season. Unlike the Wenatchee site, the HVAC energy use is a smaller fraction of the total load. One factor is that the climate is warmer in Carlton. More importantly, however, the air source heat pump is more efficient than an electric resistance furnace.

Table 2. Consolidated End Use Data for Heat Pump Conditioned Site 11418

Site 11418	**# of days**	**kWh/day**				**% of Service Load**
End Use		**Mean**	**SD**	**Min**	**Max**	
HVAC	173	15.5	13.8	0.0	59.8	47%
DHW	173	6.9	4.0	0.9	19.0	21%
Appliances (non-DHW)	173	4.4	2.4	1.7	14.2	13%
Plugs	173	1.0	0.8	0.0	2.9	3%
Lights[3]	102	0.5	0.5	0.0	1.8	1%
Total Submetered	173	28.3	16.3	2.9	83.1	85%
Whole House Service	173	33.2	16.5	6.1	90.9	100%

In addition to summary statistics, it is also possible to conduct analytical exercises with the data. Figure 8 plots HVAC energy use versus outdoor temperature. The electric resistance furnace has two stages (ER and ER_2), which nearly always operate simultaneously. The clean behavior on the graph indicates that the load is well regulated by the thermostat. The graph also shows the plug-in heater (ER_3) energy use, which appears relatively flat versus outside temperature. This sort of pattern implies that plug-in heaters may be more appropriately classified as a plug load responding strongly to occupant whim, rather than a load that responds only to outside temperature. Most notable is an encouraging, orderly relationship between outside temperature and HVAC energy usage. A linear regression of total heating energy against daily outdoor temperature results in 3.6 kWh/day-°F, or a heat loss rate of 511 Btu/hr-°F. For a home with 1,875 square feet of conditioned floor area, this heat loss rate is well within expected bounds. Last, the graph in Figure 9 shows some cooling energy use, corresponding to the end of May and beginning of June when average daily outdoor temperatures are near 70°F and the daily maximum temperature was much warmer (almost 90°F on some days according to the five-minute data).

[3] Lighting data only for 102 days due to manual downloading. This biases the lighting fraction low in the table.

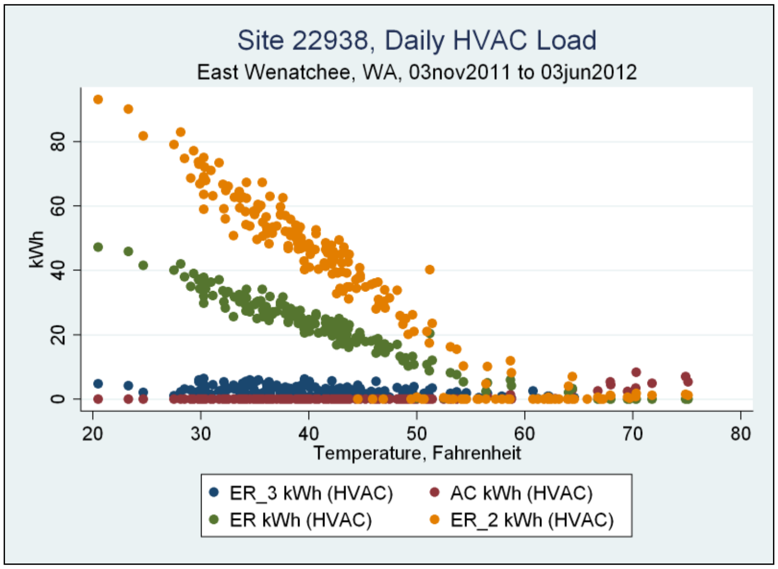

Figure 8. Daily HVAC Energy Usage Versus Outdoor Temperature

3.2. Lighting Data

The region has never conducted a thorough lighting time-of-use study. Time of use logging is challenging since it requires deployment of about 20 lighting loggers in each home and manual retrieval of data. These data can be combined with lamp/fixture information to calculate lighting usage. The first look at the data shows very promising results. (At press time, visits to pick up the remainder of the first year of time of use lighting data are being scheduled.)

Figure 10 depicts hourly lighting load shapes at one house, which has occupants who work outside of the house during the day. The occupants get up in the morning, use the bedroom and bathroom lights between 6:00 a.m. and 7:00 a.m., and then presumably leave the house. Lighting usage picks up again around 4:00 p.m. and 5:00 p.m. with the living room lights. Note that the y-axis shows average kilowatt hours per hour (kWh/hr) for each named lighting group.

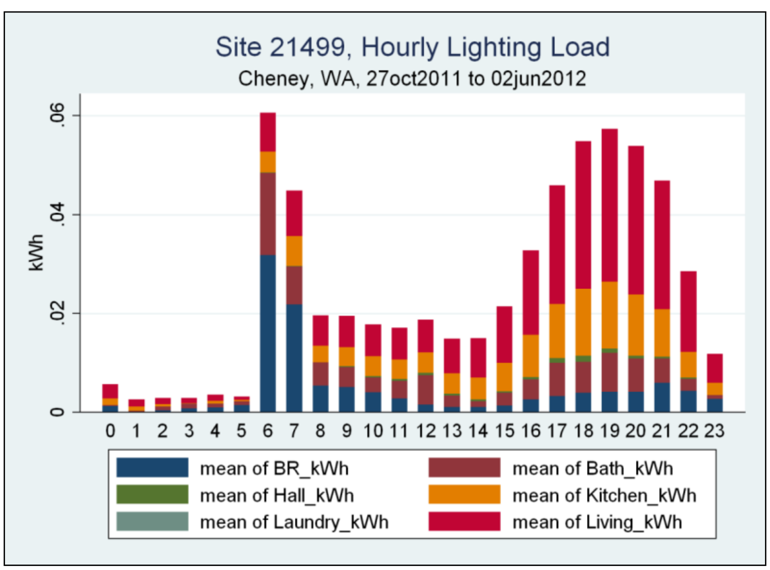

Figure 11. Hourly Lighting Load Shape – Site 21499

The daily load shape in Figure 14 also shows an expected pattern for a site where the occupants work outside of the home during the week. The Monday to Friday usage is about half of the Saturday and Sunday usage. In contrast, other sites (where homeowners are either retired or work from home) exhibits a mostly flat lighting load every day of the week.

4. Conclusion

Results from the 100 site Residential Building Stock Assessment Whole House Energy Use Study are key inputs to the 7th Northwest Power and Conservation Plan. The data collection system for this study was designed to achieve high rates of useful data recovery. A full report on the project will be available in early 2014. Because of this work, the Pacific Northwest region will have a better chance of identifying future energy conservation opportunities.

5. References

[1] Northwest Power and Conservation Council. September, 2012. *Regional Technical Forum 2011 Annual Report and 2012 Progress Update*. More in-depth information can be found at http://rtf.nwcouncil.org/.

[2] Eckman, T. (Manager of Conservation Resources for the Northwest Power and Conservation Council). 21 March 2013, Personal Communication.

[3] Pratt, R., et al. December, 1990. *Significant ELCAP Analysis Results: Summary Report. End Use and Consumer Assessment Program.* Pacific NW National Laboratory, Report PNL-6659. Prepared for Bonneville Power Administration under Related Services Agreement for US Dept. of Energy, Contract DE-AC06-76RLO-1830. Download at http://dropbox.nwcouncil.org/ELCAP%20Data/ELCAP%20Data%20From%20PNNL/Reports/ELCAP_Analysis%20(2).pdf.

[4] Baylon, D. et al. October 2012. *Residential Building Stock Assessment: Single Family Characteristics and Energy Use*. Prepared by Ecotope, Inc. for Northwest Energy Efficiency Alliance. Download at http://neea.org/docs/reports/residential-building-stock-assessment-single-family-characteristics-and-energy-use.pdf?sfvrsn=8.

[5] Pigg, S. and D. Cautley, 2010. *Energy Use by Residential Gas Water Heaters: A Technical Field Study in 10 Wisconsin Homes*. Wisconsin Energy Center.

ATLETE II –
Verification of the energy label and ecodesign declarations of washing machines

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ATLETE II - Appliance Testing for Energy Label & Evaluation – Washing Machines

Co-funded by the Intelligent Energy Europe programme

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Abstract

The ATLETE II project is developed between May 2012 and October 2014, with 11 consortium partners from across the EU. The main project goals are to assess the pan-EU compliance of washing machines with energy labelling and eco-design requirements, to identify the potential problems in the use of the testing conditions of the new standard, to improve the capacity of testing laboratories, to stimulate co-operation among national Authorities for effective market surveillance, and to support the dialogue among main stakeholders: suppliers and Market Surveillance Authorities. ATLETE II objectives are:

- Carrying out a pan-European assessment of the compliance of 50 washing machines, semi-randomly selected on the European market on the basis of agreed criteria, to the new energy labelling and ecodesign regulations through the verification of the:
  - ✓ formal compliance; check the availability of the label, product fiche and booklet of instructions provided with each appliance to the relevant requirements
  - ✓ compliance of the declared values through laboratory measurements
- Improving the know-how and testing capability of a group of laboratories having to face the more complex test conditions of the new standard: EN 60456:2011
- Verify through the field work the applicability of the new standard for the measurement of the washing machine energy and functional performance
- Support actions undertaken by the market surveillance authorities (MSA) upon the notification of the testing results highlighting products non-compliance.

The ATLETE II achievements will also include a detailed analysis of the test reports, assessing:

- the non-compliance cases: discussion of the reasons for non-compliance, in view of the revision of the washing machine labelling/ecodesign regulations
- the applicability of EN 60456:2011: in depth analysis with all the laboratories involved to evaluate the limits/problems of the new test method, if any, with a view to its improvement.

Background: history of the project – testing refrigerators

The first ATLETE project ("Appliance Testing for Energy Label Evaluation")[1] was run between 2009 and 2011, with ISIS (Research and consultancy firm, Italy), CECED (European Committee of Domestic Equipment Manufacturers), ENEA (National Agency for New Technologies, Energy and Sustainable Economic Development, Italy), ADEME (French Environment and Energy Management Agency) and SEVEn (The Energy Efficiency Center, Czech Republic) as the project partners.

That project focused on testing refrigerating appliances for their compliance with the energy label declarations and it was the first European wide testing activity focusing on market surveillance of an EU policy measure, encompassing the laboratory testing of 80 semi-randomly selected (randomly selected by a notary from certain pre-defined market segments) refrigerating appliances. The project described in detail the results of product tests and confirmed the feasibility and affordability of market surveillance.

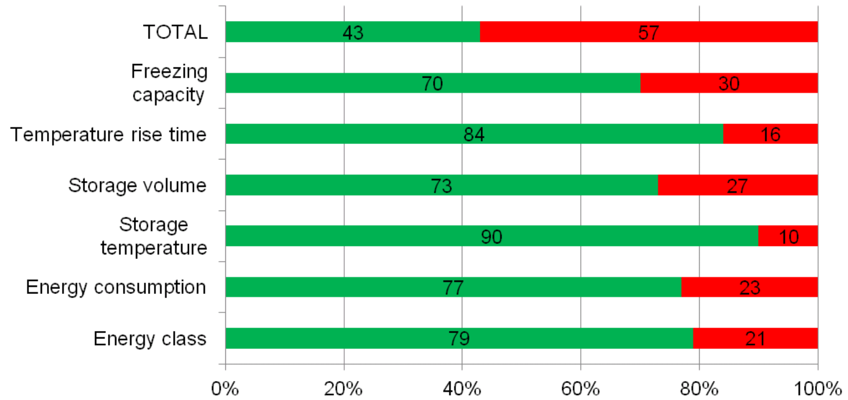
One of the main project conclusions was that by using an agreed methodology, defined taking into consideration the international experience, market surveillance activities for household appliance energy labelling are, technically feasible, and cost effective, and an essential element in meeting energy efficiency targets.

The final test results show that 80% of appliances subjected to testing and for which testing has been concluded complied with the energy efficiency class declaration and the two related key parameters: energy consumption and storage volume. But when all five parameters (see graph below) are taken into consideration, 57% of them do not comply with at least one of the test parameters.

In 25 cases, the manufacturers accepted the results of Step I (a single unit of the model under evaluation tested) and agreed to make specific remedy actions, such as the correction of the label declarations and/or of the product fiche, the improvement of the product's documentation and user's manual, as well as the printed and web catalogues. In some other cases the production of the model was discontinued. In a specific case, due to the ATLETE test result findings, a manufacturer has discovered - and then solved - a problem having occurred in the production of batch of products. Another example of improvement also includes product updates for the succeeding model range, if the original model was no longer distributed after the publication of the test results.

Test results and test reports for each individual model are publicly available on the project website and have been shared with the EU Member State Market Surveillance Authorities, media, experts and stakeholders.

Figure: Overview of test results (%) of refrigerating appliances from the first ATLETE Project



(Red (right) = non-compliance / Green (left) = Compliance)

[1] www.atlete.eu

ATLETE II – a new exercise on washing machines

The ATLETE II[2] (Appliance Testing for Washing Machines Energy Label & Ecodesign Evaluation) project evaluates energy labelling and ecodesign compliance for the second most important appliance in terms of energy use in European households: the washing machine. The project lasts between May 2012 and October 2014, is supported by the European Commission's Intelligent Energy Europe (IEE) programme[3] and is conducted by eleven partners from seven different countries.

By assessing the compliance of washing machines to labelling and ecodesign ATLETE II aims to help Member States to improve the market surveillance of the EU legislation.

Energy labels and ecodesign requirements are crucial drivers for market transformation towards more efficient appliances and phasing-out of the least efficient models. In addition, consumers should be sure that the products found on the EU market comply with the legislative requirements. The goals of the ATLETE II project are to check the pan-EU compliance of washing machines with energy labelling and eco-design requirements using the new measurement method, to improve the capacity of testing laboratories and at the same time support co-operation among national Authorities for effective market surveillance.

ATLETE II encompasses:

- Detailed evaluation of the current level of market surveillance activities related to labelling and ecodesign compliance around the EU
- Semi-random selection (methodology explained on page 6) of 50 models of washing machines from the EU markets for assessing the compliance with the energy label and ecodesign requirements (except noise and standby)
- First large-scale laboratory testing of a washing machine under the new Energy labelling legislation, also applying a new measurement method: EN 60456:2011
- Organisation of mini-ring tests among some EU laboratories, ensuring improved quality and consistence in testing washing machines
- The publication of all project results, from the list of models selected for testing, through all methodologies applied, to test reports, and overall evaluation of results
- Inviting manufacturers, whose models will be tested, for undertaking voluntary remedy action in case of suspected non-compliance of their products
- Informing EU Member State Market Surveillance Authorities about all individual test results relevant to models sold on their own markets
- The organisation of EU-wide and national dissemination activities informing the stakeholders about the project's testing procedures and the consumers on the label requirements
- Concrete support to the EU and national authorities for an effective energy labelling and ecodesign implementation and verification

Through ATLETE II the project team seeks to confirm that compliance verification testing for market surveillance can be done in a systematic, effective and cost-efficient way, thus setting a major cornerstone in supporting market transformation and ensuring the highest benefit for consumers, manufacturers and the environment. Key stakeholders in the project include Market Surveillance Authorities, laboratories, suppliers, energy efficiency experts, and consumer and environmental protection organisations.

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[2] http://www.atlete.eu/2/

[3] http://ec.europa.eu/energy/intelligent/

Excerpts from the project actions and results achieved[4]

Overview of market surveillance activities

One of the introductory steps of the ATLETE II project was the organisation of a survey, collecting and evaluating detailed information about the level of market surveillance activities undertaken by individual EU member states. This survey evaluated the organisation and level of activities of national Authorities related to the new commitments envisaged by the new legislation on ecodesign (Directive 2009/125/EC) and labelling (Directive 2010/30/EU) including the obligation for member states to report to the Commission and then to the Parliament on the achieved market compliance (see Art 3.3 and whereas 10 of directive 2010/30/EU).

The following aspects of the Energy label and ecodesign verification, with a specific focus on washing machines, have been researched:

- Budget available for surveillance activities
- Number of staff and inspectors available
- Number of shop inspections undertaken, including the results on compliance, types of shops visited, online shopping, etc,
- Number of product tests performed, including available information on test results and their analysis
- Complaints received from physical or legal persons
- Number of non-compliant products found on the market
- Nature of the corrective action taken and the products withdrawn from the market
- Sanctions applied and / or voluntary measures taken by companies

The survey on market surveillance activities in all member states was conducted in early 2013[5] and summarises the level of Market Surveillance activities in individual EU countries, related to product labelling and ecodesign, with a specific focus on washing machines.
The survey provides an overview on the quantity and quality of activities, e.g. the number of product testing), review of shop visits undertaken to verify the presence of energy labels, and the opinion of the market surveillance authority representatives on the possible future enlargement of the label surveillance activities:

- Majority of MSA (6 MS out of the 7 MS who provided feedback on product compliance level) estimate that the current compliance rates for energy labelling and ecodesign requirements of washing machines are approximately similar as other products.
- There is a lack of financial resources allocated to market surveillance activities from national governments as reported by six of the eight MS who do not conduct testing of products.
- Testing facilities/laboratories are insufficient at MS level and EU-wide. Majority of MSA consider the current testing costs to be expensive (6 out of 8 MS who do not perform tests reported costs as a barrier), and may be time intensive (5 out of 6 MS who provided feedback on testing period commented that it can last up to few months).

[4] Status of the project as of March 2013, submission of EEDAL 2013 paper
[5] http://www.atlete.eu/2/market-surveillance-authorities

- With the transposition of the new Directives, some (8 MS) market surveillance authorities faced human resources constraints. These constraints are primarily associated to the new work associated with these legislations. This is because although 11 MS accepted impact on their activities however only 3 of them had a corresponding change in their staff.
- Around half (6 MS out of 13 MS) of the MS that test products held detailed records of the compliance level of washing machines.
- Almost half (11 MS out of 23 MS who responded) of the MS currently control the compliance of catalogues. Control of catalogues is planned to increase regardless of the fact that their use is not widely spread among consumers in some MS.
- More than half (13 MS out of 21 MS who responded) of the MS currently control the compliance of internet sales. Control of internet offers will further increase in coming years as 5 out of the 8 MS who do not perform a control on internet offers at present, intend to do it in future.

Definition of the compliance verification approach

The main methodological approach for cost effective product compliance verification prepared within the previous ATLETE project has been re-assessed and tuned-up to adapt it to the washing machine verification. This update intends to eliminate the inconsistencies of some actions and elements that have been identified during the field work on refrigerating appliances, and the draft: *Guidelines for WM verification: models and laboratories selection, new standards and measurement methods* was prepared and published in the project website[6]. The aim of the Guidelines, which will be finalised at the end of the project, is to describe in detail a globally applicable procedure for the verification of the compliance of this product group to the implementing measures under the eco-design framework Directive 2009/125/EC and the energy labelling framework Directive 2010/30/EU. It is worth noting that within the ATLETE II project testing activities, the conformity verification of the washing machines will follow the essential requirements included in the EU legislation: a two Step verification procedure will be developed, testing first one single unit of the model under investigation.

Since one of the aims of this project is to contribute to increasing the quality of information and test reports received from individual laboratories a Test Report Template was prepared[7]. The template is aimed at improving the comparability of the test results and as a supporting tool for MSA when deciding about the compliance of a tested product. Laboratories participating in ATLETE II testing were asked to deliver their own test reports and to fill in the Test Report Template at least for the reporting of the test results of the first batch of washing machines. This will allow the template to be checked to confirm whether it is sufficiently developed to be used as the only test reporting system for the project, or if it requires further improvement. A decision will be taken by the project partners also on the basis of the comments received by the test laboratories.

Selection of washing machine models for testing

ATLETE II foresees the testing of 50 models of washing machines, covering suppliers with both a large and small market share. Based on the previous successful experience with the refrigerating appliances, the selection of the washing machines is done among the best seller models for each supplier. In particular it was decided to select:

- the bestseller products for each manufacturer/producer that has a market share above 0.1% on the EU 27 market,
- and national champions in following countries AT, BE, CZ, DK, FR, DE, IT, NL, PL, ES, SE, UK with market share above 1%,

[6] http://www.atlete.eu/2/doc/DraftGuidelinesforWMverification_September2012.pdf
[7] http://www.atlete.eu/2/test-procedures

- 5 washing machine models for each of the expected 4 manufacturers with a Market Share (MS) ≥ 10% (for a total of 20 models);
- 3 models for each of the expected 4 manufacturers with 5%≤MS<10% (for a total of 12 models);
- 2 models for each of the expected 4 manufacturers with 1%≤MS<5% (for a total of 8 modes)
- 1 model for each of the expected 4 manufacturers with 0,5%≤MS<1% (for a total of 4 modes)
- and 6 models randomly selected for the remaining 252 manufacturers with a market share < 0,5%.

The model selection process is organised following a 'semi-random' approach:

- the market is divided into market segments (based on the selling levels) - from the segment of best sellers to the segment of least sellers
- an independent company was tendered to deliver the overview of the market, including the individual models sold and their market shares and country availability, based on which the individual models have been selected
- in each of these segments, some washing machine models were randomly selected by an external notary
- models are purchased by an independent partner of the project (ICRT) and delivered to the laboratories.

The overall total is thus 50 washing machines models. Models will be selected in three batches, in order to decrease as much as possible the time to testing, i.e. the time from the selection of the model to be tested and the actual testing. This approach is expected to reduce at least partially the possibility that a selected model disappears from the market before the two step verification procedure is completed.

As of February 2013, 13 models have been selected[8] and laboratories started to perform product testing. When the full testing of all (50) models will be completed (spring 2014), the project will publish not only the list of models tested, but also the results of tests and the test reports from individual laboratories.

Voluntary protocol for manufacturers proactive participation

Manufacturers have access to the testing facilities to assist the procedure of testing their own products under a supervision of the laboratory and project representatives. All known manufacturers have been also invited to sign a voluntary protocol[9], by which, should their products be suspected of being non-compliant after the development of Step 1 of the verification procedure, they will have the possibility to stop the testing and, to take remedy actions to reflect the test results.

Within the ATLETE II project the protocol has been circulated to all known manufacturers of washing machines. By signing the protocol, the individual manufacturers confirm that they will:

- take, within 30 (calendar) days after being informed of the testing all the remedy actions necessary to correct the energy labelling declarations of the appliance model/s concerned in accordance with the results of the testing procedure, alternatively modify the product to make it comply with its energy label declaration; and
- take, within 30 (calendar) days after being informed of the results of the testing all the remedy actions necessary to fulfil the eco-design requirements for the appliance model/s concerned; and

[8] http://www.atlete.eu/2/doc/ListOfTheSelectedModels
[9] http://www.atlete.eu/2/doc/ManufacturersParticipationProtocol.pdf

- inform, within the same timeframe the ATLETE II Project Leader of the remedy actions taken to correct the energy labelling/eco-design declarations or parameters, and provide the ATLETE II Project Leader with the appropriate evidence of conformity and remedy actions taken, such as a copy of a letter sent to the trade, with a proof of the sending thereof, and a copy of brochures or leaflets marketing or advertising the concerned appliance model/s with the correct energy labelling/eco-design declarations, without disclosing any information which would be confidential.

The voluntary protocol has been circulated to the individual manufacturers before the selection of models for testing had been undertaken in February 2013. Out of 128 brands contacted, 27 manufacturers, covering approximately 90 % of the EU market share and minimum 41 out of 50 models to be tested have signed the protocol. The list of the manufacturers signing the protocol is available on the project website[10].

Selection of the test laboratories

One of the key project activities, ensuring that the project would deliver high quality results, was to select laboratories that would ensure a high capability of testing washing machines. The project has therefore organised a thorough selection procedure including[11]:

- Call for interest: independent laboratories in the EU known for being able to test washing machines have been invited to express their interest to participate to the call for tender, which took place by July 2012. The Call for tender was published also on the project website to allow all laboratories to participate
- Laboratory recognition Questionnaire: a detailed questionnaire[12] was circulated to the laboratories expressing their interest to participate to the project, asking for a confirmation of their intention to participate to the project, and collecting a large set of technical information about testing capability, instrumentation, calibration as well as laboratory experience, certification and personnel qualification and training. 9 laboratories, out of the 20 invited laboratories, have submitted the full information requested. The requirements to participate included for example:
  - Independent laboratory status
  - Ability to test automatic horizontal axis washing machines according to EN 60456:2011 and related standard(s)
  - Capability to fully follow the given test method (EN 60456:2011) without in-house interpretation of test conditions
  - Readiness to accept a visit of an expert from the project partners and of the representative of the manufacturer(s) of the tested unit(s)
  - experience in previous Round Robin Tests/Performing tests for washing machines and relevant models tested over the past years
  - periodic training of technicians who will perform the tests
  - confirmation on accuracy of equipment, including meters and calibration frequency
  - Regular supply of the consumables (i.e. standard detergent, load, etc.) needed to test washing machines from a well-known source
  - Capability to test all testing requirements for energy labelling and ecodesign.

[10] http://www.atlete.eu/2/manufacturers
[11] http://www.atlete.eu/2/laboratories
[12] http://www.atlete.eu/2/doc/LaboratoryrecognitionQuestionnaire.pdf

- Visit of external expert – before confirming the final selection, the laboratories have been personally visited by two experts appointed by the project to check the responses given in the questionnaire.
- Finally, an economic offer was asked to the laboratories, through a Call for Tender. The score achieved with the offer has been then combined with the score achieved in the Questionnaire and the overall result lead to the selection of six laboratories:

1. CTTN (France),
2. IMQ (Italy),
3. INTERTEK (UK),
4. LCOE (Spain),
5. SLG (Germany),
6. VDE (Germany).

It is expected that on average 8 to 10 models will be tested by each laboratory.

A coordination meeting with the selected laboratories took place in February 2013, and three more meetings will take place within the project, to share the experience, discuss individual testing procedures and ensure the same level of reporting to be delivered.

International Advisory Committee to the project

An International Advisory Committee (IAC) is also organised within the ATLETE II project. The IAC consists of national experts, stakeholders, MSA, representatives of the civil society, etc. IAC participants contribute to the formulation of the overall procedure, project activities and to the discussion of the specific outcomes.

The advisory committee has been established[13] at the start of the project and first two of the three foreseen meetings were held in November 2012 in Brussels and in May 2013 in Stockholm.

Other next steps

Development of mini-Round Robin Tests

Parallel to the compliance verification of the selected washing machines ATLETE II foresees that a mini-Round Robin Test exercise is developed to improve the experience of the existing testing laboratories around Europe. The aim is to support the creation of a sufficient testing capacity for an effective market surveillance action by the national Market Surveillance Authorities.

The exercise is open to laboratories able to test washing machines and not already contracted by the project. Laboratories participation is on voluntary basis, for free, and subject to some conditions. ATLETE II project will be responsible for the logistic and the purchase of some of the consumables (test loads, standard detergent, standard test strips) and for the calibration of the reference washing machine. Washing machines having passed the compliance verification tests will be circulated for the mini-Round Robin Test exercise.

The number of laboratories to be involved in the mini-Round Robin Test (at least 3 labs for each mini-ring test are needed for a meaningful statistical analysis of the tests results) and the overall number of mini-Round Robin Test will be decided considering the positive answers received to an invitation sent to a list of laboratories in February 2013

[13] http://www.atlete.eu/2/project-resources/category/5-meetings-with-target-groups

Harmonised application of the new standard for washing machines

The aim of this action is to analyse, with the contribution of all partners and involved laboratories the content of the new standard EN 60456:2011, to evaluate possible areas of uncertainty of its application in order to create – if needed - a common understanding and application of the test conditions. In this respect, if necessary, a set of recommendations to the EU Commission/DG ENER, the standardization bodies, the laboratories and the other involved stakeholders will be prepared at the end of the project

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A Proposed Framework for Moving Towards International Comparability of Appliance Energy Efficiency Policies

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Abstract

Alignment of appliance energy efficiency policy components enables consistent policy comparison around the world. Numerous policies exist, put in place product-by-product by individual economies; increased alignment can conserve national resources while accelerating policy impacts. Harmonization entails the convergence of critical elements of an appliance efficiency policy, including: test methods; product definitions/categorization; energy efficiency/performance metrics; and performance threshold tiers.

This paper proposes a framework for how to direct appliance standards and labeling analysis resources to promote greater international policy alignment. The approach includes four interrelated elements:

1. Analyzing gaps in existing policies ("gap analysis")
2. Evaluating test methods and policy stringency across economies ("benchmarking")
3. Developing suitable international standards to serve as the foundation for aligned efficiency policies
4. Tailoring information to inform economy-specific policy developments

First, policy gap analyses reveal "low-hanging fruit" on the international and national level. Second, a product benchmarking study can identify the source and magnitude of differences in existing test methods which inhibit international comparison, and provide the basis for conversion functions among energy efficiency metrics and test methods from various economies.

Third, international standards bodies such as IEC and ISO can improve the quality and comprehensiveness of international standards, encoding aligned policy elements to facilitate greater policy convergence. Finally, tailored analysis of the aforementioned information can identify the most important policy matters for consideration in a particular economy.

This technical and analytical framework for greater international harmonization of appliance efficiency policy should lead to more successful alignment of appliance energy efficiency policies around the world.

Introduction

Harmonization – the alignment or convergence of critical elements of one or more appliance efficiency policies – facilitates the comparison of policies around the world, which has the potential to promote faster and greater improvements to the stringency of energy efficiency standards and labeling (S&L) policies. Since policies are put in place product-by-product by individual countries, the quantity of policies in place is huge; increased alignment can save countries time and money while accelerating policy impacts. The elements of appliance efficiency policies that might be harmonized, or aligned, include test methods, product definitions and categorization, metrics for energy efficiency or energy performance, and performance thresholds.

It is important to note that the goal of harmonization is not to have *identical* global energy efficiency policies for all types of products; rather, it is to encourage incremental and responsible progress towards convergence. For example, it is likely that policy elements for globally-traded products such as televisions and computers can be made more consistent across economies than can policy elements for products such as air conditioners that are designed to serve climate conditions in specific markets. Harmonization objectives for air conditioners may therefore entail development of a menu of regional policy options to accommodate the range of expected climate conditions.

The benefits of convergent international energy efficiency standards are well characterized, as outlined below. [3]

- *Enhanced transparency and clarity across economies*. Aligned policy elements permit direct comparison (and benchmarking) of product efficiency and policy stringency across peer economies, and can inform prioritization and S&L policy decisions.
- *Lower cost, higher quality, more rapid, and more ambitious domestic regulations*. Harmonized policy elements facilitate the use of analyses from peer economies to determine techno-economic potentials from higher energy efficiency levels and justify the adoption of regulations set at specific energy efficiency levels.
- *Lower costs and higher quality of tests.* The cost and expertise needed to develop and maintain test procedures is shared.
- *Reduced manufacturer costs for testing and production.* Globally-traded products that attain a harmonized energy efficiency rating will be accepted for sale in any economy that adopts the policy elements concerned.
- *Accelerated market and manufacturer learning, lower consumer costs, and stimulation of innovation.* A common set of energy efficiency thresholds supports the market for high efficiency products, since manufacturers know that products that meet a given performance threshold can be sold on a larger market. This drives up the volume of higher efficiency products, lowers the production costs through economies of scale, and thereby accelerates market transformation.
- *Facilitated technology transfer*. Given the certainty that efficiency thresholds are globally linked, manufacturers have greater long-term incentives to pioneer even more energy-efficient products to meet aspirational thresholds, thus facilitating technology transfer.

Presently, a greater degree of harmonization is taking place at the regional level than at the global level [1]. Some of these regional harmonization efforts aim to establish identical policies and policy elements even for appliances with large usage variations based on climate or behavior. The EU, for example, has regional S&L policies for many of these appliances. S&L policies are often harmonized within North America, especially between the US and Canada. Additionally, the 15 economies that form the Economic Community of West African States (ECOWAS) are developing a regional policy on energy efficiency that involves "a harmonized policy, legal and regulatory framework in energy efficiency for the ECOWAS region, including energy efficiency labels and standards." [2]

This paper proposes a comprehensive framework for how to direct and apply appliance S&L research and analysis resources to promote greater international policy alignment. The approach includes four interrelated elements:

1. Analyzing gaps in existing policies ("gap analysis")

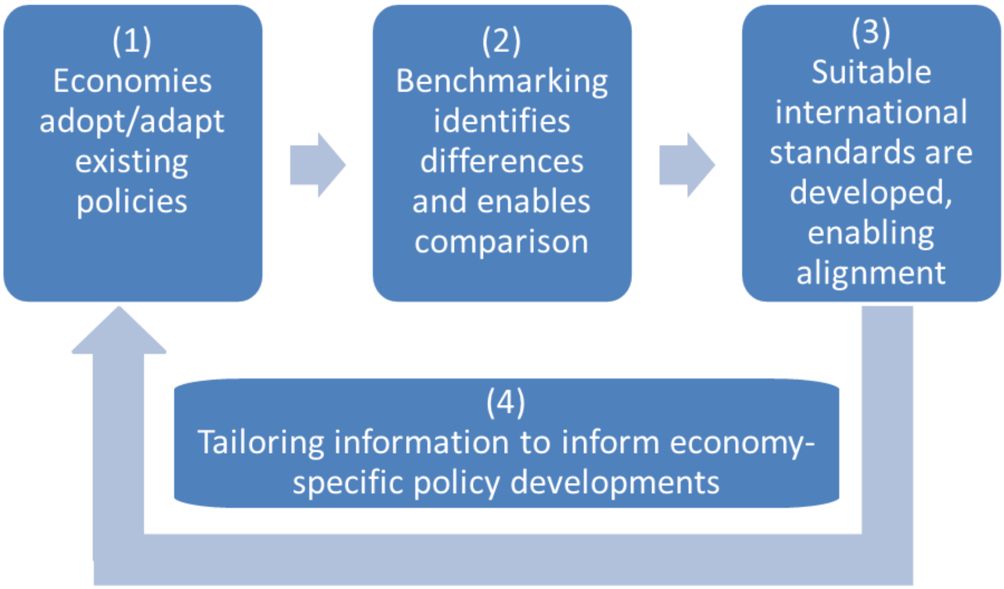
2. Evaluating test methods and energy efficiency policy stringency across economies ("benchmarking")

3. Developing suitable international standards to serve as the foundation for aligned efficiency policies

4. Tailoring information to inform policy developments in individual economies

By establishing a technical and analytical foundation for greater international harmonization of appliance efficiency policy, this framework should lead to more compelling and successful efforts to develop appliance energy efficiency policies that may be readily adopted by economies around the world.

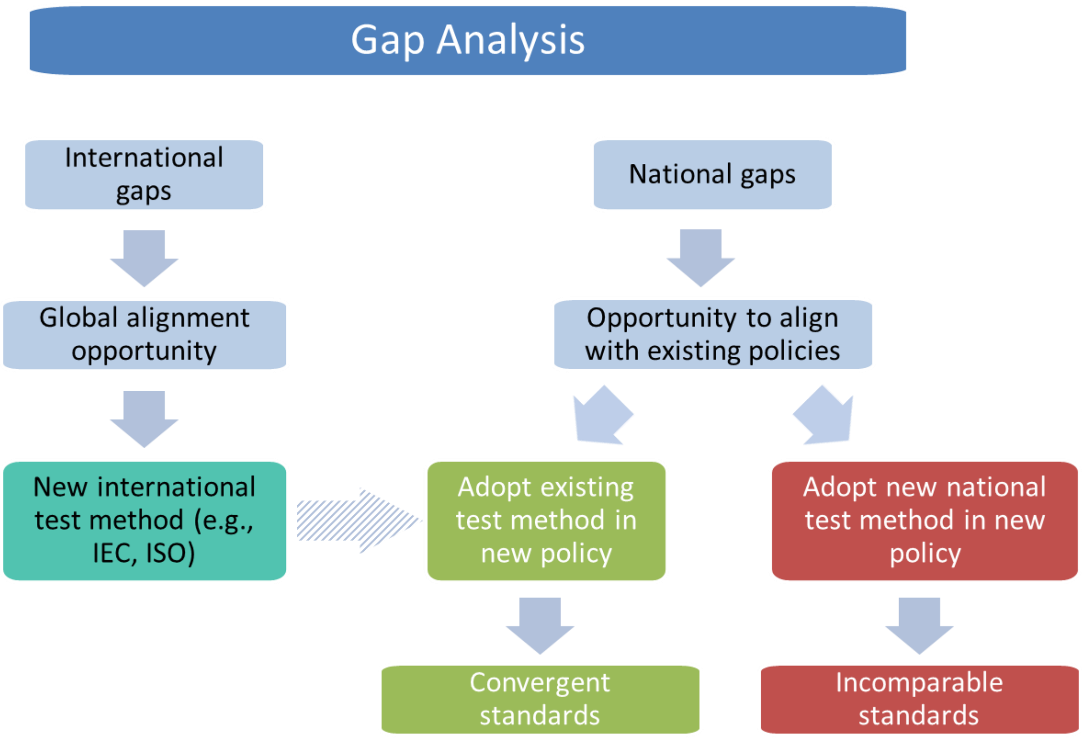
Figure 1: A proposed methodological framework for promoting greater international convergence of S&L policies and policy elements



Gap analysis of existing policies

As a first step, S&L practitioners can assess the energy-saving potentials available for different products through convergent S&L policies, and use that information to define policy priorities. A policy gap analysis reveals "low-hanging fruit" on the international and national level. Product categories that lack international energy efficiency test methods present opportunities for international standards bodies, such as IEC and ISO. Similarly, product categories for which there are few national energy efficiency policies present opportunities for decision makers to adapt policies from other countries, thereby filling policy gaps and increasing international comparability.

Figure 2: Gap analysis reveals "low-hanging fruit" for S&L policies, and can lead to aligned standards

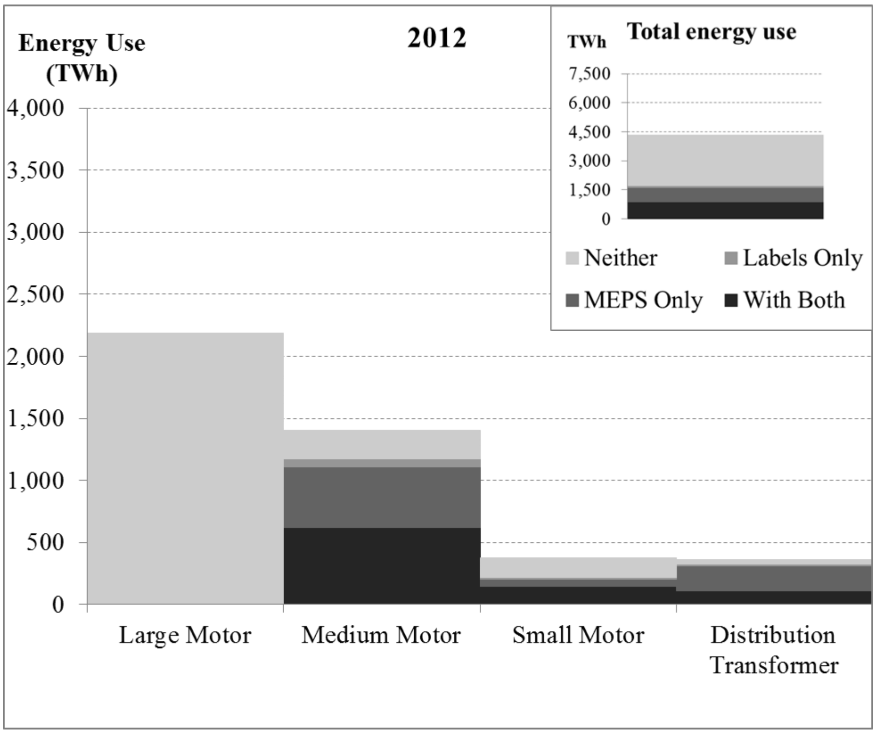


Sparsely regulated product categories: immediate global harmonization opportunities

One barrier to harmonization is a resistance to change in countries with long-standing S&L policies in place. Once domestic manufacturers, standardization bodies, and regulators have invested in the development and maintenance of a particular policy infrastructure, products may be designed to reflect the nuances of domestic test procedures, product classifications, and efficiency metrics [3].

Therefore, it is likely easier to establish convergent S&L policies for products or product categories that are sparsely regulated around the world. Gap analyses will reveal products that have less international S&L coverage and therefore would face fewer engrained structures within existing S&L programs. Figure 3 shows a gap analysis for several major energy-using products in the industrial sector, and illustrates that large motors use a large amount of energy but are not covered by S&L policies anywhere in the world. Medium-sized motors, however, are well-covered by S&L policies; furthermore, those policies are largely harmonized around the world, as will be discussed below in the section, "Facilitation of convergent international efficiency policies".

Figure 3: Energy use of industrial electric motors and distribution transformers in 2012: an example of a product-focused gap analysis [4]



Commercial refrigeration equipment, for example, has relatively few S&L policies in place around the world (i.e., mandatory or voluntary minimum energy performance requirement, comparative label, or endorsement label). Based on the CLASP S&L Database [5], only 8 economies currently have any S&L policies in place for commercial refrigeration equipment: Australia, Canada, China, Japan, Korea, Mexico, New Zealand, and the US.[1] For comparison, residential refrigerators have S&L policies in place in 35 economies. From this simple gap analysis, it is apparent that internationally-convergent S&L policies and policy components for commercial refrigeration equipment will face fewer barriers from existing S&L programs.

For these sparsely regulated products, establishing effective international menus of policy settings can also ease the path for national regulators to broaden S&L policy coverage; if an international standard is suitable to be adopted for use in an economy, it lowers the cost and time required by that economy to cover that product.

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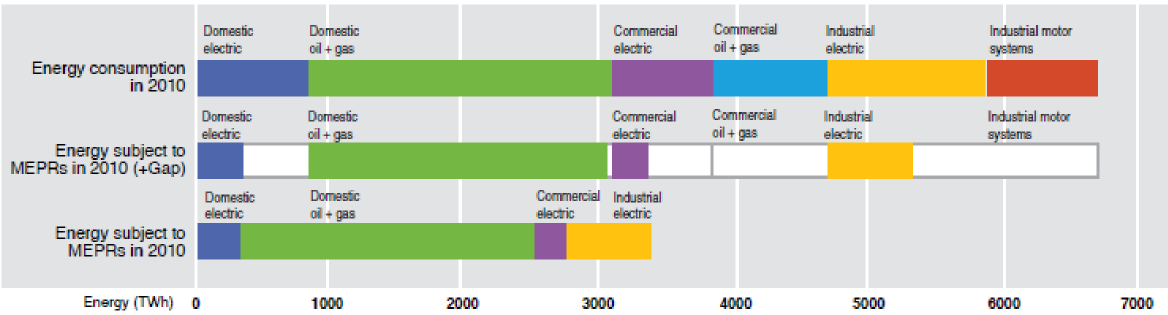
[1] As of 20 March 2013, the EU has policies under development for commercial refrigeration equipment.

Gaps within individual economies: opportunities to adapt existing policies

Performing a gap analysis for a specific economy shows what products or product groups are not covered. In many cases, these products are covered in other economies, providing policymakers with a starting point from which they can adapt their own S&L policies. Figure 4 shows a gap analysis for the EU based on regulations and energy use in 2010, and illustrates that the commercial and industrial sectors in the EU have far more room to increase policy coverage than the residential sector.

Figure 4: EU energy consumption and energy subject to MEPS in 2010: an example of a high-level economy-specific gap analysis [3]

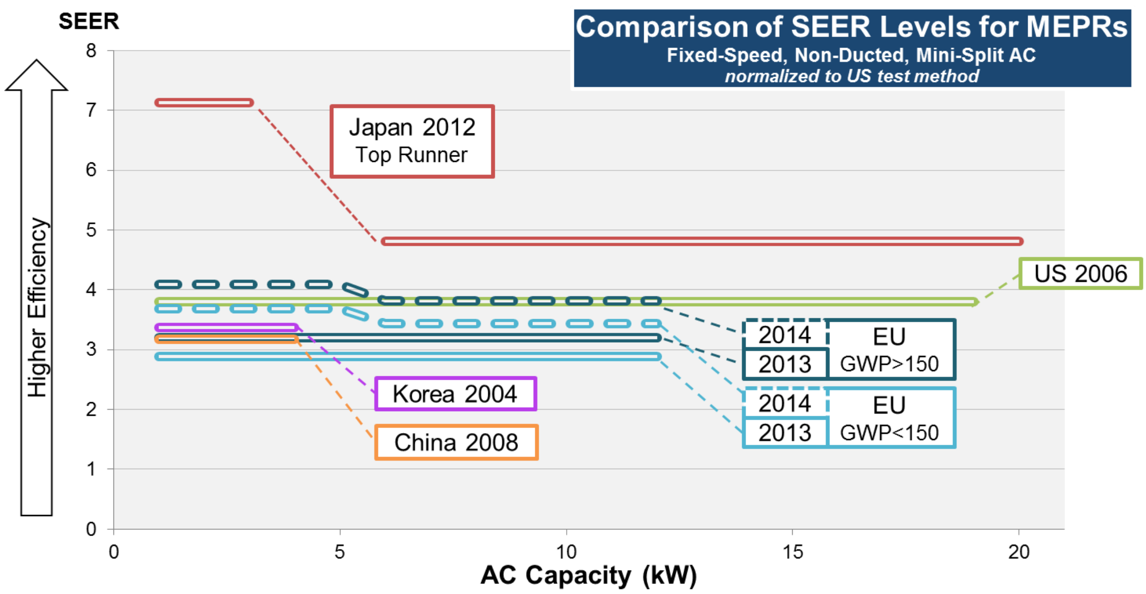


Adaptation of existing S&L policies sometimes results in divergent policy components; the causes for this divergence can be identified through a benchmarking analysis, as described below. The analysis can be used to highlight important technical issues to consider when developing future policy components to maximize future convergence, as described below in the section "Facilitation of convergent international efficiency policies".

Product benchmarking analysis

After assessing potentials and setting priorities, the second step is for S&L stakeholders to analyze existing policies and markets, and in doing so to document current best practices. A benchmarking analysis focuses on a particular product in a group of selected economies to examine existing S&L policies, identify best practices, and characterize the most efficient models on the market. By doing so, benchmarking analyses lay the foundation for strong and comparable energy performance requirements around the world.

Figure 5: Benchmarking efficiency of room air conditioners: an example of a benchmarking analysis [6]



Benchmarking analyses address another major barrier to global harmonization of appliance efficiency policy: a lack of national resources to put towards a comprehensive review of global policies, and thus understand how national policies compare to those in peer economies [3]. Figure 5 shows the results of a benchmarking study for room air conditioners that compares the minimum energy performance standards of several economies despite variations in test procedures and efficiency metric formulas. Figure 5 shows that Japan had the most stringent energy requirements for split room air conditioner units.

In order to compare policy stringency, benchmarking analyses must convert among divergent energy efficiency metrics and test methods from the selected economies. Because of this, benchmarking studies can generate conversion functions that define how to translate product S&L policy among these economies. In the absence of fully harmonized test methods, these conversion functions allow regulators some means of evaluating the stringency of a proposed policy against policies in peer economies, thereby enabling them to identify opportunities for policy improvement.

Going one step further, the generation of those conversion functions often requires a deep understanding of the source and magnitude of variations in existing test methods that otherwise inhibit international comparison. Identifying these differences can provide a path towards convergence of the policy components – once S&L stakeholders have an understanding of the variations, there is a clear direction towards addressing those differences.

Facilitation of convergent international S&L policies

Once S&L policymakers understand the variations in existing S&L policies and policy components, the third step is for international standardization processes to facilitate greater policy convergence. This can be achieved through the development of technical solutions in response to the pathways outlined through the expanded benchmarking analysis.

International standards bodies such as IEC and ISO can encode and disseminate best practice policy components in their standards. These informative classifications may include all of the key policy elements: test methods, product definitions and categorization, metrics for energy efficiency or energy performance, and suggested efficiency thresholds. For example, an air conditioner test method may include a series of test conditions that represent the various global climate zones plus conversion factors with which to compare test results depending on which test conditions are used. Policymakers could then choose to reference the test conditions most appropriate for their climate, and the results would still be comparable with other global policies based on the same test method.

An example of this type of approach exists today in the IEC standard for mid-size industrial electric motors [7].[2] The IEC developed a test method suitable for international use along with a series of recommended efficiency thresholds. The test method was subsequently adopted by many economies around the world, each of which then selected the efficiency threshold most suitable to their particular policy and local market needs. For stakeholders with diverse market transformation interests, this approach provides a single menu of thresholds from which to select efficiency levels for MEPS, labeling thresholds, and financial incentives.

The process of developing suitable international energy efficiency standards involves close coordination between policymakers and technical committees of international standards bodies. A comprehensive benchmarking analysis can provide a framework for a constructive dialogue, enabling stakeholders to focus on the specific factors within dissimilar test methods that create divergence.

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[2] These motors are single-speed, three-phase cage induction motors with a rated output between 0.75 kW and 375 kW, and run on 50 or 60 Hz.

Table 1: Relationships between international and domestic efficiency thresholds for motors [3]

Motor efficiency	**Inter-national (new/old)**	**US**	**EU**	**China**	**India**
Aspirational	**IE4**			**2010: Grade 1 label**	
Premium	**IE3**	**2010: MEPS level** (a) 2001: Voluntary label (b)	*2015: MEPS for most motors*	**2010: Grade 2 label** (d) 2006: Grade 1 label	*2014: Recommended MEPS* **2011: Top label class**
High	**IE2** Eff1	1997: MEPS level (c)	*2015: MEPS for motors with VSDs* **2011: MEPS level**	**2010: Grade 3 label** **2006: MEPS level**	**2011: Medium label class; Recommended MEPS** (e) 2004: Top label class
Standard	**IE1** Eff2				**2011: Lowest label class** 2004: Lowest label class
Below standard	Eff3				

Current regulations are in **bold**; past regulations are in standard font; future regulations are in *italics*.
Notes:
(a) Based on Energy Independence and Security Act of 2007 (EISA); effective in 2010
(b) Voluntary label was called NEMA Premium and was based on industry consensus
(c) Based on Energy Policy Act of 1992 (EPAct); effective in 1997
(d) In China, the highest efficiency motors are represented by Grade 1 labels; efficiency decreases as Grades increase.
(e) The recommended MEPS in India are voluntary.

International efforts such as the Super-efficient Equipment and Appliance Deployment (SEAD) Initiative and the IEA-4E Implementing Agreement are among the organizations exploring ways to improve coordination between governments and standards organizations in pursuit of this goal.[3]

Tailoring policies for a specific economy

Once suitable policy foundations are in place, the fourth and final step is for economies to adopt the choices from the policy menu that are best suited to their climate, behavior, and economic conditions. This step is critical to achieving the maximum benefits of harmonization, since it translates international analysis and best practice into actual national policy. Tailored analysis for an individual economy can highlight the most appropriate policy options for consideration, and can also make policymakers aware of best practice examples they may not have otherwise considered.

In addition, a cost-benefit analysis of the selected policy options for a product can demonstrate to policymakers the potential benefits of such policies to domestic regulators, manufacturers, and consumers. Outlining the benefits in this way can create the political will needed to move from analysis to action, encouraging policymakers to undertake new policy development or policy revision to align with international standards. This assessment also contributes to policymakers' decisions regarding which efficiency threshold makes sense for adoption within their economy.

[3] More information about ongoing coordination efforts by the SEAD initiative and IEA-4E can be found online here.

Conclusions and recommendations

It is useful to begin with a global perspective to achieve the goal of local adoption of convergent appliance efficiency policies. Through gap analyses, the global view can point policymakers and technical experts to the least-regulated products globally, which should offer near-term opportunities for harmonization – resulting accelerated, cost-effective policy implementation – with few barriers from existing policies. This big-picture view can also direct national policymakers to low-hanging fruit – existing policies in other economies that can be adapted to meet national conditions.

For products that are subject to S&L policies around the world, benchmarking analyses can be used to determine which economies have the most stringent policies, and can provide conversion factors by which to translate among different economies' policies. Close examination of test methods in these analyses can result in a pathway for international standardization bodies to develop policy options suitable for different climate, behavioral, and economic conditions that exist in economies around the world.

Finally, if international standards bodies craft technical standards that work for the full range of global economies, then a cost-benefit analysis can take into account local conditions to determine the best specific policy set for an economy. This analysis can also generate political will for increasing the scope or stringency of S&L policies by illustrating to policymakers the potential benefits of adopting these internationally harmonized policies.

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Are Test Procedures Passing the Test? Ensuring That Measured Results Are Representative of Energy Use in the Field

Chris Calwell

Ecova[1]

Abstract

In every test method designed to measure the performance and energy consumption of a product, there is a natural tension between emphasizing precision and repeatability on the one hand, and representativeness and relevance on the other hand. It is very difficult to optimize both simultaneously. The way consumers use products in the real world can be complex and unpredictable. In response, lab technicians often specify a simplified duty cycle and set of operating conditions for each type of product in order to measure its performance and energy use in a precise, repeatable way.

However, as residential energy-using products have evolved and their capabilities have broadened, energy efficiency test procedures have often not kept pace. Instead, to minimize manufacturers' test burden, policymakers have become increasingly content measuring aspects of a product's behavior and energy consumption that diverge significantly from the way those products are actually operated in homes. They then often apply rough mathematical correction factors to "true up" the results to real-world conditions. This causes problems when different technologies behave in the real world in fundamentally different ways that cannot be corrected uniformly, especially when policymakers employ the resulting data sets to establish voluntary and mandatory efficiency specifications.

They can develop *precise*, but often *inaccurate* estimates of the real-world energy and carbon savings that will result from the adoption of their policies. In effect, as the old adage goes, we cannot manage what we do not measure. Our laboratory test methods should capture, to the maximum extent possible, the actual energy use that occurs when products are operated in the real world by their purchasers. Likewise, we should reward manufacturers for design changes that yield meaningful savings *under those conditions*. Theoretical or potential energy savings are far less useful, both to governments seeking to reduce greenhouse gas emissions, and to product purchasers, seeking to reduce energy bills.

This paper will examine three cases in particular where this problem has arisen (automobiles, refrigerators, and clothes dryers). It will summarize early efforts by governments and researchers to modify those test procedures to more realistically reflect their products' actual operating characteristics. The paper will also lay out a set of guiding principles that can be followed in future test procedure development and revision processes to minimize these problems, and to correct for observed differences between test procedure energy use and field energy use, both when products are new and when they have been operating for a significant period of time.

Introduction

> *It is the mark of an educated man to look for precision in each class of things just so far as the nature of the subject admits. --Aristotle*

Global efforts to improve the energy efficiency of consumer products have made impressive headway in recent years, after repeated iterations of mandatory energy performance standards, voluntary and mandatory energy labeling programs, and financial incentives to encourage the sale of the best products. Indeed, we might assume from all of the efficiency gains that have been achieved in various consumer products that absolute energy consumption is dropping in a sustained way. But there is much left to do.

Refrigerators are perhaps the most commonly cited example of that success story. The average new US model has about 15% more adjusted interior volume than it did in 1972, yet consumes about 75% less electricity on the federal test procedure and costs 55% less to purchase in constant dollars (Figure 1).

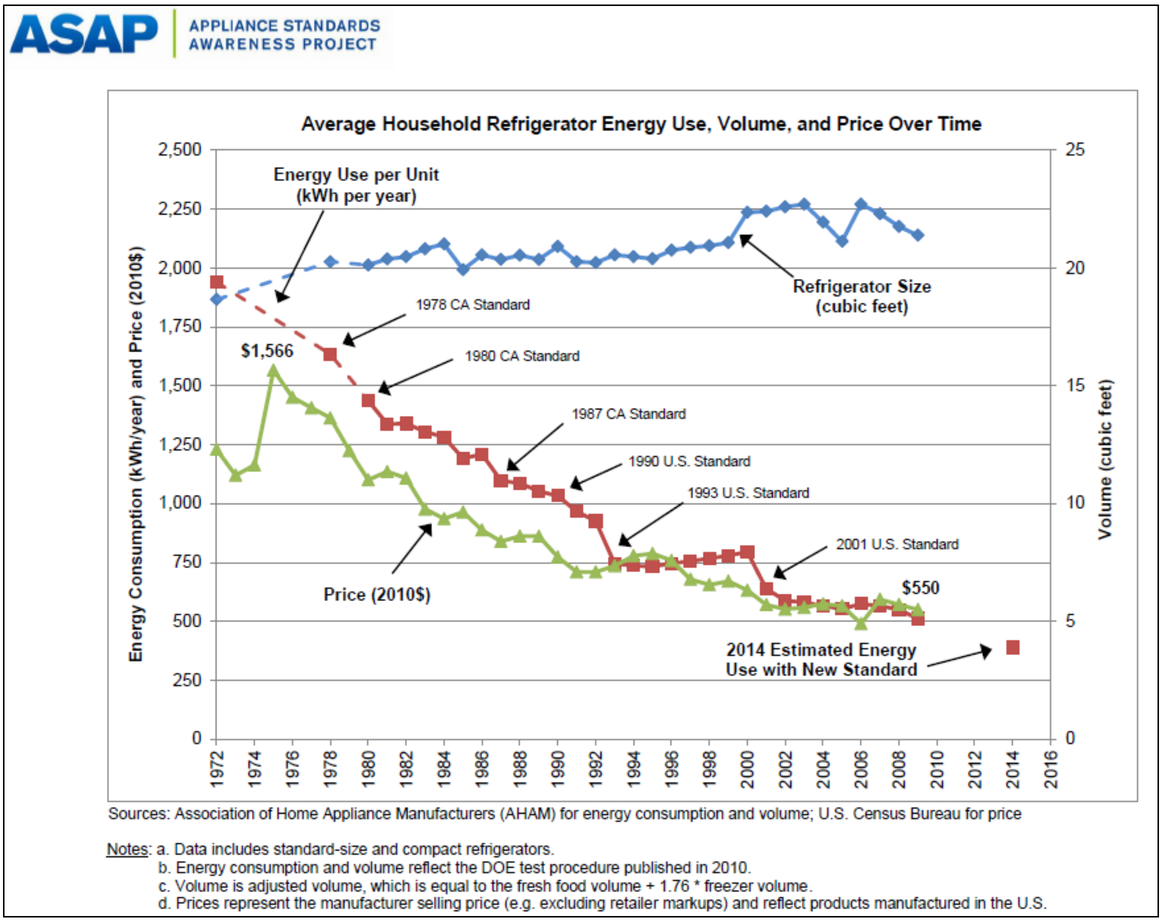

Figure 1. Average household refrigerator energy use, volume and price over time (Source: Appliance Standards Awareness Project)

European and Asian markets have also managed impressive improvements in refrigerator efficiency, yet the total energy consumed worldwide for residential refrigeration continues to rise. Why?

As noted in my earlier research for eceee and ENERGY STAR, a multitude of other factors influence total energy use beyond their energy efficiency, including steady growth in the global population, the number of refrigerators per person, and the average size and feature content of each refrigerator.[2] To the extent people upgrade and replace them more often, the efficiency of the average unit in use more closely approaches that of the newest models. However, the total amount of energy consumption associated with manufacturing, transporting, and ultimately recycling or disposing of them continues to rise as well. These factors and others are captured in a holistic equation (Figure 2) known as IPALUCEMD that attempts to address more comprehensively the overall greenhouse gas emissions impacts of a given product category:

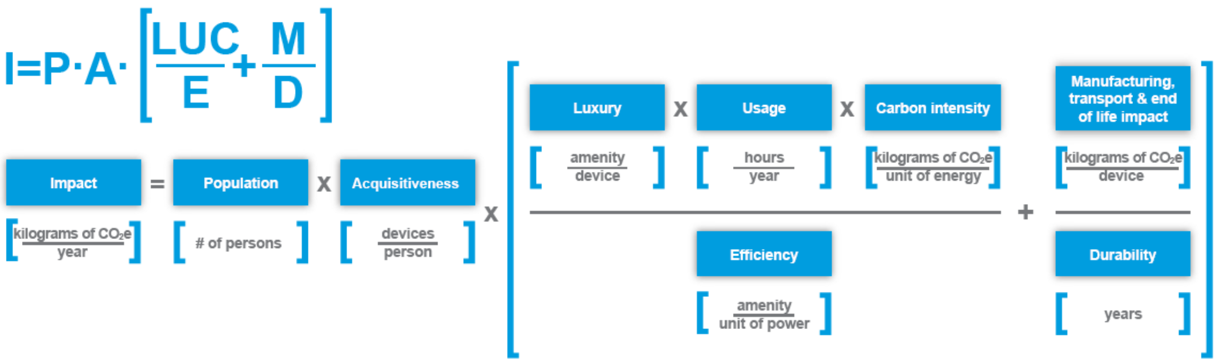

Figure 2. IPALUCEMD equation

What this formula illustrates is that a product's greenhouse gas emissions can, and routinely do, keep rising even as that product becomes more energy efficient, because so many other attributes of that product are changing in ways that increase its environmental impact.

But what if even product efficiency is also not improving as much as we think? What is missing from this formulation is any recognition that the efficiency of a new product being measured in a laboratory test procedure might differ meaningfully from its operational efficiency in a home environment, when operated by a typical user.

The Limitations of Test Procedure Results

Test procedures, methods and standards have been in widespread use for so many years that the energy efficiency community often finds itself conflating laboratory-measured energy consumption or efficiency with a product's *actual* energy performance in use. While they are indeed intended to be close or at least proportionate to each other, the degree to which that is actually achieved varies widely, both within a given end use and over time, as technologies and user behaviors change.

Paul Waide noted in a 2008 IEA presentation [3] that the ideal test procedure is:

- Reproducible
- Repeatable
- Produces measurements of an appliance's energy consumption and service provision that are representative of those in real use
- Inexpensive
- Universally recognized.

He then stated that "in reality, it is hard to find the right balance between these factors and many compromises are needed."

His list is similar to that offered by Alan Meier and James Hill in a seminal 1995 paper [4] on the question of what an ideal test procedure should do:

- Reflect actual usage conditions
- Yield repeatable, accurate results
- Accurately reflect the relative performance of different design options for a given appliance
- Cover a wide range of models within that category of appliance
- Be inexpensive to perform
- Be easy to modify to accommodate new technologies or features; and
- Produce results that can be easily compared with results from other test procedures

Meier and Hill also offered a cogent summary of the inherent tradeoffs and compromises associated with trying to optimize for so many attributes at once:

> *Clearly, an energy test procedure is a compromise: it does not fully achieve any of the criteria for an ideal test, but it satisfies enough of them to discourage excessive complaints. At a minimum, a ranking of different models by their tested energy use should correspond reasonably close to a ranking by the models' field energy use. An additional danger of compromise is that manufacturers may optimize performance for a test procedure that does not assure energy savings in the field.*

Manufacturers of the affected products and their trade associations typically have the largest financial stake in the outcome of test procedure deliberations and the greatest resources of any of the interested parties to contribute to the effort. Their engineers are also intimately familiar with the design and operation of the technologies being measured, which underscores the value of having them involved in the test procedure development process. But if they lead it or dominate it, their natural inclination will be to optimize those aspects of the test procedure that are of highest priority to them -- low cost to conduct, high repeatability and reproducibility, and universal recognition – all of which can help to minimize the engineering and legal costs associated with complying with mandatory efficiency standards and labeling programs around the world.

These are understandable, laudable goals, but the broader public interest is not being served unless test procedures also yield results that are realistic and representative of actual use. The public policies that brought these test procedures into existence or formalized their use nationally were created to help consumers understand and reduce their energy bills. Consumers can and should reasonably expect that a product labeled to use 20% less energy than another will, in fact, deliver those savings in typical use. If not, the extra money they spent purchasing the better product may have been wasted, or the money they spent on utility bills for an inefficient product not so labeled may have been equally wasted.

Meier and Hill correctly predicted, in 1995, how this mix of issues would play out over the coming decades:

> *As countries work to establish energy efficiency standards, the details of every test procedure will come under more scrutiny. Manufacturers will seek to make the testing requirements simple and inexpensive. Foreign manufacturers will regard complex or unique test procedures as a trade barrier. In addition, domestic manufacturers will want to ensure that their products appear as energy efficient as possible, while consumers will want the test procedures to reflect as realistic results as possible. Meanwhile, continuing technological innovations will undermine the ability of existing procedures to reasonably represent an appliance's energy efficiency.*

We have arrived at that juncture, and are paying the price, to varying degrees depending on the product type and the associated government agency.

The Vehicles Example

One striking example is associated with vehicles. The US Environmental Protection Agency developed two test procedures for determining vehicle fuel efficiency in 1975 – one for highway and one for city driving. [5] The maximum speed encountered under either test is 60 mph and the maximum acceleration is 3.3 mph per second, meaning that it would take 18 seconds to reach 60 mph from a standing start.

Because EPA has been carefully tracking various aspects of vehicle performance since 1975, it is possible to see how different vehicle performance has become from the test procedure conditions with each passing year. [6] Today's vehicles commonly accelerate from 0-60 mph in about 8 to 10 seconds, and the most powerful cars do so in half that time. So the majority of new cars being tested in the US can accelerate two to four times faster than these test procedures are capable of measuring. That effect of this difference, not surprisingly, is that the energy efficiency of vehicles in normal driving conditions is often not as high as the efficiency derived from the test procedure and published on the vehicle's window sticker. This gave birth to an American phrase, initially applied as a manufacturer disclaimer to EPA fuel efficiency ratings vehicles, and now used to describe any situation in which one individual's results may differ from typical ones: "your mileage may vary."

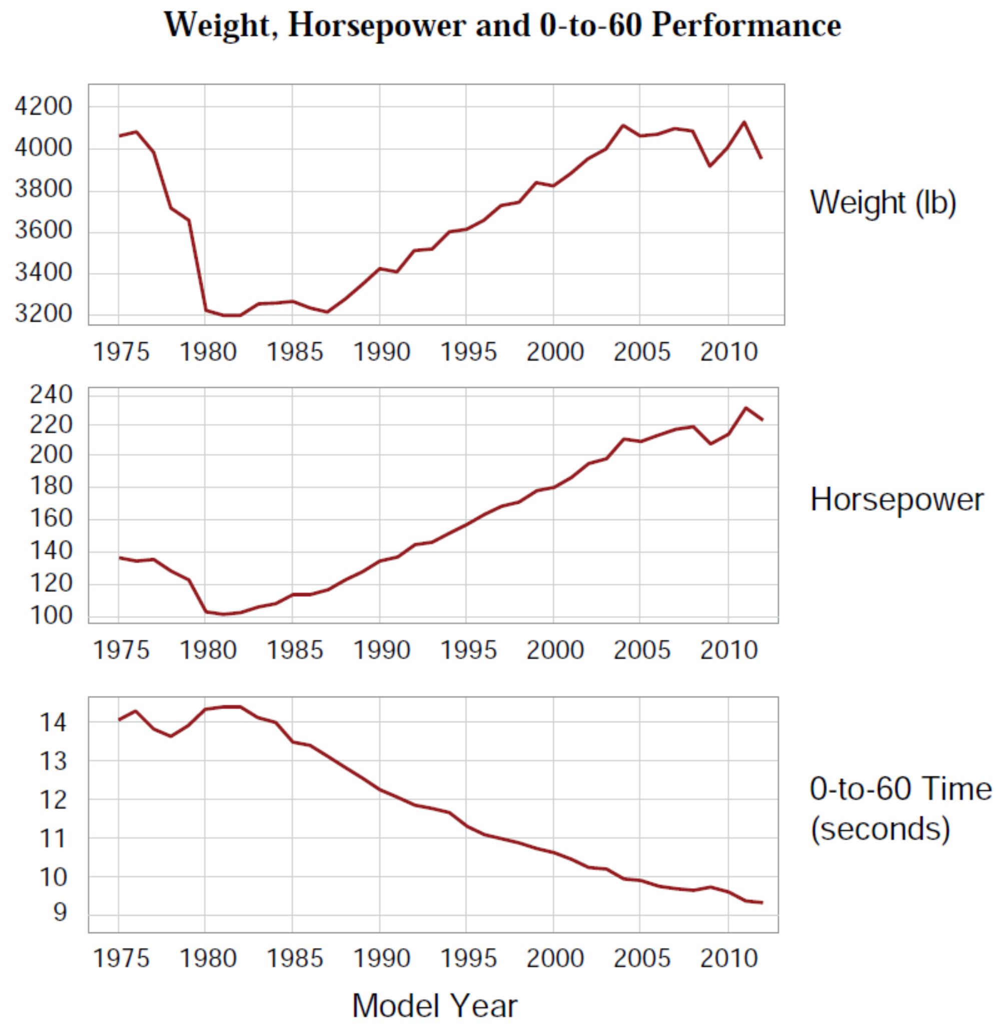

Figure 3. EPA data on US vehicles over time

Average acceleration times in US vehicles have dropped virtually every year since 1983, even while vehicle weight continues to rise, in part because of steady increases in available horsepower. Vehicle test procedures use a laboratory dynamometer to simulate a vehicle's weight, tire rolling resistance, mechanical friction, and aerodynamic drag and operate at a fixed ambient temperature of 75 degrees, so give up a considerable degree of realism and representativeness in the interest of achieving a high degree of repeatability.[7] Such vehicles experience no differences in weather, road conditions, accessory usage, weight of passengers and cargo carried, elevation, or any of the variables routinely encountered by any of us on a typical drive.

In response to criticism that its test procedures no longer represent real world driving conditions, EPA recently developed three more tests to capture the impacts of high ambient temperatures (95 degrees F) with the air conditioner running, cold start behavior at low ambient temperatures (20 degrees F), and harder accelerations and higher speeds (brief periods of operation at 70 to 80 mph). These were laudable improvements, and helped to reveal that many cars had lower "real world" efficiency than the previous tests had indicated. Typical city fuel economy values dropped by an average of 11%, and highway fuel economy values dropped slightly less. It was not uncommon for hybrid vehicles to see fuel economy drops of 12 to 20%, in part because their hybrid technology offers the most efficiency benefit at low speeds and at moderate ambient temperatures – not the conditions the new EPA tests were examining.

But rather than require the use of those new procedures to determine the fuel economy of all new vehicles, EPA allows manufacturers to apply mathematical correction factors instead to the results derived from the 38-year old test procedures. Not surprisingly, the majority of manufacturers have opted to use this correction factor approach for the majority of new models they test, obtaining optimistic numbers for expected fuel economy and lower compliance costs. Testing by consumer magazines has now shown that new Ford hybrid vehicles like the Fusion and C-Max are consistently achieving 17-21% worse fuel economy in actual driving conditions than predicted by their EPA-certified fuel economy ratings. When the vehicles are driven even more aggressively by magazine testers, their fuel economy can be as much as 32% below claimed values.[8] These kinds of discrepancies are leading to lawsuits and disgruntled purchasers, in part because the federal testing has failed to deliver the very service it was created to provide – a reasonable prediction of how many miles a particular vehicle will travel per gallon of fuel consumed.

Government agencies that manage test procedure development may update them infrequently, with or without an explicit intent to refine their approach as new field data become available. Two recent examples from the US Department of Energy (DOE) are illustrative: refrigerators and clothes dryers.

The Evolving Refrigerator Success Story

The US government has for decades been testing refrigerators at ambient temperatures of 90 degrees F, without placing food inside, opening and closing the product door during operation, or operating the refrigerator's included icemaker. The first factor tends to overestimate energy use relative to actual operating conditions, while the other mostly factors tend to underestimate it. However, we cannot intentionally err on both sides of reality in the hopes that the opposing factors will cancel out, especially when the physical mechanisms by which the energy losses occur are different.[9]

Warmer temperatures increase heat gains through the exterior of the refrigerator and cause its compressor to operate less efficiently. Putting room temperature food in the refrigerator causes it to work harder, while filling it with already-cooled food can help it maintain thermal mass when the door is opened. Opening the door causes a replacement of cooled air volume with ambient air that must be cooled again to the desired temperature. Likewise, refrigerators need a significant amount of energy per year to operate their automatic icemakers and detach the ice from cooling trays. This was a small enough share of total annual energy use to be ignored when refrigerators used more than 1,500 kWh/year, but not now, when the most efficient models can use less than 400 kWh/year. These mechanisms explain some of the observed differences in new models, but those differences can become greater over time, as discussed further below. Refrigerator compressors, insulation, gaskets, and heat exchanging coils can simply become less effective over time due to loss of lubrication, or dirt and dust build-up, or mechanical wear.

Measurements conducted in the field and in the laboratory when California utilities were collecting and recycling old refrigerators revealed the extent of these problems. [10] Of the 157 refrigerator models for which an original Energy Guide label value could be located for annual energy use, the average value found was 1,274 kWh/year. Yet measurement of those refrigerators in the homes where they were found suggested an average energy use of 1,573 kWh/year, or 23% more than the label value. Even more interestingly, when those refrigerators were taken back to the laboratory to have their original DOE energy efficiency test repeated, their average energy use was 1,809 kWh/year, or 42% more than the original label value. In both cases, the variation was quite inconsistent from model to model, with in situ (field) measurements often reflecting *lower* energy consumption than the original Energy Guide label value. Simply applying correction factors of 23 or 42% to the original Energy Guide label values would not have consistently predicted the consumption of individual models after multiple years spent in the field.

However, the results did show that utilities could save more energy, at least initially, than originally expected by replacing older refrigerators with highly efficient new models. It also meant that utilities needed to monitor degradation over time, to better understand how those savings might persist in the newest refrigerator designs.

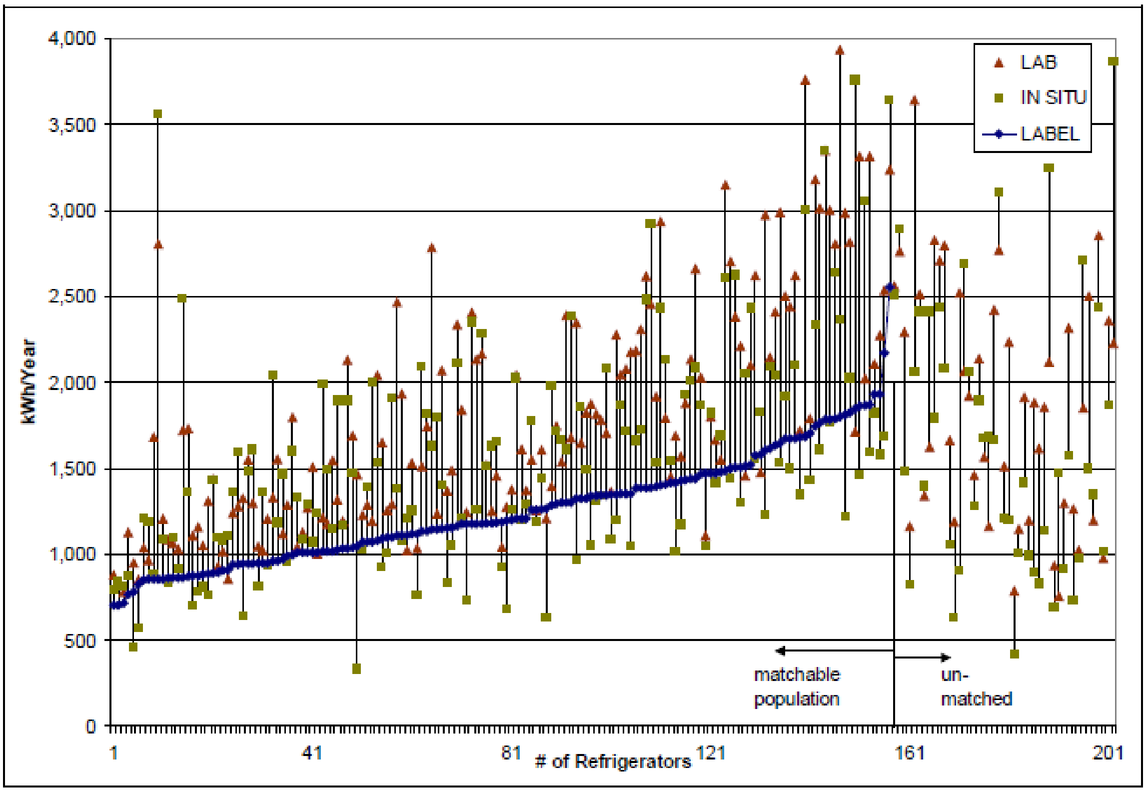

Figure 4. Measured differences in older refrigerator energy use in the field

Given the concerns expressed by multiple stakeholders to its appliance standards process, DOE recently commissioned a comprehensive and mathematically robust analysis [11] of multiple refrigerator field measurement studies conducted over more than a decade. This helped DOE understand the extent to which field energy use of refrigerators was diverging from test procedure values, and the principal causes of that divergence, providing the government with a sound technical basis for updating its test procedure over time and its near-term energy savings analysis. The result was an increase of 0.35 quads in the expected energy savings from refrigerators and freezers over a 30 year period, yielding $1.57 to $4.1 billion of additional net present value benefits to society over that timeframe.

Clothes Dryers: The Challenge of Obtaining Meaningful Energy Savings from a Constrained Test Procedure

By contrast, clothes dryers in the United States have long been considered an appliance where all of the available models have similar efficiency and few options exist to significantly improve energy efficiency. Yet they are the largest source of US residential energy consumption for which there are no ENERGY STAR or Energy Guide labels in place, and no incentives or promotions by utilities to encourage the sale of the most efficient models.[12] Yet, empirically, we know that clothes dryer energy use varies widely. When the Florida Solar Energy Center researchers placed identical clothes dryer models into identical houses in the same part of Florida, they found variation in clothes dryer energy consumption from 949 to 2,592 kWh/year, largely driven by differences in number of occupants per home and the behavior of those occupants.[13]

When different clothes dryer models of various sizes and ages are added into the mix, observed differences in annual energy use become even greater, and operational efficiency differences contribute strongly to that. Recent field measurements by the Northwest Energy Efficiency Alliance (NEEA) found that dryers in homes were drying an average of 2.4 pounds of clothing per kWh of electricity consumed, while the DOE test procedure predicted efficiencies of 3.7 to 4.2 pounds of clothing per kWh for similar dryer models. [14] While some of this can be attributed to differences in initial load size and moisture content, the degree of duct restriction observed in homes, and the variety of settings and modes selected by users, one of the largest observed causes of variation was the load composition itself. Typical laundry users place items in their dryers that are simply and obviously more difficult to dry than the thin, two-dimensional, uniformly sized, 50% synthetic test cloths utilized by DOE. These cloths are prized by DOE for the precision and repeatability they bring to the testing process, but they behave differently than clothing and only offer slight advantages in repeatability over the more realistic IEC test load. Real clothing is three-dimensional, having internal and external surfaces and pockets that experience differing amounts of contact with warm air in a dryer. Most of the dried items are thicker and have larger percentages of cotton content than the DOE test cloths as well, making them more likely to soak up and retain moisture than DOE test cloths. Historically the DOE test procedure for dryers has ascribed a fixed energy savings credits to dryers offering automatic termination capability as well, rather than measuring its effectiveness directly.

US DOE's recently completed clothes dryer test procedure final rule [15] represented an opportunity to correct these discrepancies. DOE asked for and received detailed, intensively analyzed, recent field data and comments from NEEA and the California utilities [16] regarding typical dryer load fabric types and sizes, initial moisture content, cycle selection preferences, degree of duct restriction, number of cycles occurring per year, and laboratory-normalized annual energy consumption data. DOE elected not to utilize any of that field data in its analysis, relying instead on two clothes dryer field studies conducted in the 1970s, manufacturer assertions of consumer usage patterns, and its own 2009 Residential Energy Consumption Survey (RECS) results. RECS ascribes portions of whole-house energy consumption in a national cross section of homes to particular end uses like washers and dryers from consumer self-reported answers to questions of approximately how many loads of laundry they wash per week and approximately what share of those loads they typically place in clothes dryers.

DOE also declined to entertain any changes to its test load composition, in its present or pending test procedure versions. This will continue to constrain the usefulness of DOE test data for dryer labeling or utility rebate program purposes, as the California utilities noted in their comments:

> *When the items being dried do not resemble what consumers actually place in their dryers, no amount of mathematical adjustment after the fact can compensate to reasonably predict how much energy consumers will use in the home if they purchase one dryer model instead of another. And isn't that the whole point of having a clothes dryer energy efficiency test procedure in the first place?*

In the end, DOE also decided not to require that manufacturers actually measure the effectiveness of their automatic termination controls to comply with mandatory federal standards – the key dryer test procedure change that both manufacturers and efficiency advocates had jointly petitioned DOE to make. This is remarkable because DOE's own testing showed that dryers that terminate properly and promptly can reduce per-cycle energy consumption by 4 to 38% (with an average savings of 20%), relative to dryers that do not. Instead, DOE made the use of a new and more realistic test procedure *voluntary* – able to be used by manufacturers who wish to participate voluntarily in the newly proposed ENERGY STAR labeling program for clothes dryers. The likely effect of having two fundamentally different test procedures for clothes dryers operative simultaneously in the US will be that inefficient products will continue to be measured the old way and efficient products will increasingly be measured the new way, leading to inaccurate estimates of how much energy could be saved by switching from one to the other.

DOE did, however, eliminate a proposed 0.8 "field use factor" that would have had the effect of arbitrarily reducing by 20% the measured energy use during an automatic termination cycle. This helped to ensure that the full measured differences found in the voluntary test procedure would be visible in labeling programs, which will assist ENERGY STAR in promoting the most efficient models.

By not seeking out significant differences in dryer performance and energy efficiency in their mandatory test procedure, though, DOE indeed did not find them. It reached the conclusion in its associated mandatory efficiency standards analysis [17] that only about 5% of dryer energy use could be cost-effectively saved. Meanwhile, heat pump dryer models saving 30 to 50% of baseline energy consumption continue to achieve ever-greater market share in Europe, in part because they are tested and labeled in ways that intentionally help to reveal those differences. No heat pump dryers have yet been introduced in the US market.

The difference between the approaches to refrigerators and clothes dryers taken by the same government agency is stark and reveals a missed opportunity to save substantially more energy cost-effectively in a widely used appliance.

Causes of Divergence between Laboratory and Field Measurements of Product Energy Use

The case studies referenced above provide some examples of the reasons for major differences between laboratory and field measurements, but it can be helpful to understand them more generally. Even products that are new, can, and routinely do, behave differently on efficiency test procedures conducted in a laboratory setting than they do in a typical home or office environment, for a variety of reasons:

- Test procedures are often conducted on one or a limited number of samples of a particular model, so may miss some of the sample-to-sample variation in performance that is expected when products are manufactured by workers on an assembly line.
- Ambient temperature and humidity levels can be different than those specified in the test procedure and quite variable over time, or products can be operated at a different elevation than sea level.
- Known contributors to product energy use are often intentionally ignored by test procedures, as was the case with automatic ice makers in refrigerators, air conditioning systems in vehicles, and network standby power use in many electronic products until recently.
- Workloads can vary widely and continuously, and can be much more heterogeneous than they are in test procedures. Increasingly, products have the size and capability to be used for a wide variety of tasks, so we should not be surprised if the ways they get used increasingly differ from the simplistic scenarios under which they are tested.
- Most energy-using products are capable of operating in far more modes or with a far wider variety of chosen product settings than those default or dominant conditions that efficiency procedures are intended to test. Moreover, customer preferences for particular settings can shift over time, such that defaults no longer occur the majority of the time.
- Customers can install firmware updates, external peripherals, or additional applications to electronic products that did not have them when originally tested in the laboratory, increasing power use in idle mode or decreasing the percentage of time spent in idle mode.
- Human interaction with products is unpredictable; users may start and stop a product frequently instead of allowing it to run uninterrupted, or modify its settings mid-way through, or fail to read directions about how to setup and operate a product, or simply make an intentional operational choice that goes against manufacturer recommendations.
- Manufacturers may design their products to recognize standard test conditions and behave in ways that maximize efficiency under those conditions, but not under other conditions more commonly encountered in the field.

We can characterize most of these issues as sources of *field variance*. Field variance can either be addressed in the test procedure itself, by trying to make it as realistic and representative of real world product behavior as possible, or in a mathematical term that is multiplied by the test procedure value to obtain a term more likely to resemble field performance. Addressing as much of the field variance as possible in a revised and updated test procedure is preferable, because the ways in which actual consumption can vary from measured consumption under standardized conditions are often not linear or entirely predictable from one technology to the next. A deeply flawed test procedure will not even predict the correct rank order of appliances from least to most efficient if they were measured in the field, failing one of its primary reasons to exist. It is better to ensure that the range of conditions and modes likely to be encountered in the field is fully represented in the test procedure, giving policymakers better, more meaningful data to work with in constructing duty cycles and energy efficiency metrics. Once that is done, smaller and more straightforward sources of field variance can be addressed through an adjustment factor (see below).

As CLASP researchers have recently noted [18], a second key cause of divergence is simply the fact that the majority of energy-using products in operation are no longer new, and so can experience a drop in performance and a change in energy consumption over time that together shift their efficiency. Motors and other moving parts suffer mechanical wear or fail to receive needed maintenance, lubrication or brush replacements, steadily experiencing more friction with age. Coils, fins and other heat transfer surfaces become coated with dust and dirt, losing the ability to conduct heat as readily. Insulating materials break down, phosphors degrade, dirt and dust accumulate on the surface of light-emitting and diffusing elements, and heat alters the behavior and performance of electronic components. In short, entropy is the enemy of efficiency, and time is entropy's chief ally. With each passing day, energy-using products behave less like they did when they were new, and very rarely in ways that reduce energy consumption.

We can refer to this issue as *degradation over time*. For the most part, government test procedures do not attempt to capture this effect at all; they concern themselves primarily with product performance when the product is new and operating optimally, or after, at most, a brief break-in period of operation (as with lamps). And yet, if government and utility energy planning processes assume that the savings from an efficiency measure will be steady over time, they could be counting on savings that fail to materialize in later years. Or, they could be underestimating savings if the new, efficient technologies do a better job of preventing degradation than the conventional product designs do.

Promising Solutions

Provided that the test procedure is reasonably comprehensive and realistic, what else can be done to improve efficiency estimates? Including field adjustment and degradation factors changes our equation for comprehensively addressing the greenhouse gas impacts of energy-using products as follows:

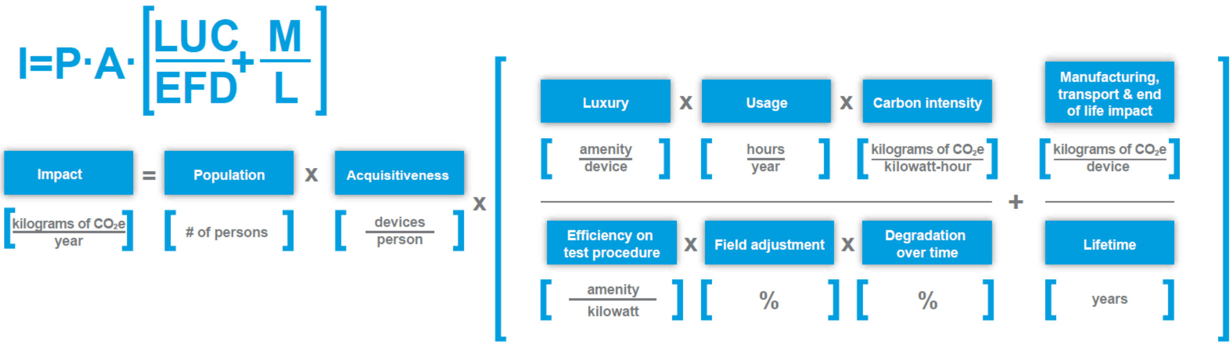

Figure 5. Proposed approach to account for energy efficiency differences in the field and over time

In this revised IPALUCEFDML equation, efficiency is now clearly labeled as "efficiency on test procedure" so as to distinguish from field or typical efficiency values in practice. Then a field adjustment percentage (upward or downward) is made to that value to better approximate real world efficiency when the product is new. Then a degradation over time adjustment percentage (upward or downward) is made to that value to better approximate the efficiency of products that might have been in use in the field for a number of years. "Durability" is also reframed as "Lifetime" in this updated equation form, in part to reduce confusion about how to measure and express that particular term. Note that many of these terms can change over time, such that the degree of luxury being delivered, or the hours of operation, or the carbon intensity of the energy source, or the degradation in efficiency performance can be different when a product is new than when it is has been in use for five years.

Beyond changes to the calculation process, however, changes to the testing *process* itself are urgently needed, and can be summarized as follows. First, measure power use in the laboratory under a precise, repeatable, and diverse set of operating conditions and modes. Put the products through their paces, so that most of the ways a consumer is likely to use them are reasonably captured and measured. Then log data in the field, in a representative sample of homes, to determine how much time products spend in each of their operating modes or performing each of their various functions. Log power consumption data in the field at the same time to confirm that a product's range of operating conditions in the field is captured by the original testing that was done in the lab. Provided that the two line up, regularly updated field data can be analyzed annually and used to update governments' annual energy usage and energy savings potential estimates for each product category. These field data can also supplement or even supplant extensive reliance on survey tools like the Residential Energy Consumption Survey (RECS) to develop baselines of residential energy consumption by device.

An analogy to cooking may be helpful in explaining the merits of a philosophical change in our approach to energy efficiency test procedures. The goal of a good test procedure should not be to correctly bake the best cake, or even to surmise the precise recipe for doing so, which will invariably change over time as consumer preferences change. Rather, the goal of a good test procedure should be to inventory as many of the ingredients as possible that might be used to bake the range of cakes people prefer, and quantify the nutritional aspects and properties of each. Armed with that information, we can help consumers understand how much fat, protein and carbohydrates they might ingest from the various types of common cakes they could choose to bake from those ingredients. The error today comes in assuming that everyone will bake the same cake – they won't. But with the answers to just a few questions about preferences for flavor, texture and portion size, the government could give many different buyers a reasonable sense of what they might expect from the resulting mix.

Similarly, there is no way to know what percentage of the time a given dryer will spend drying jeans, but if one element of the test procedure assesses how rapidly and efficiently they dry jeans, that aspect can be incorporated into the ultimate duty cycle and efficiency metric. And jeans are so widely worn, washed, and dried throughout the developed world (450 million pairs purchased annually in the US alone) [20], that it seems odd that we would decline to measure dryer performance with them at all.

The Internet makes it increasingly easy to combine those measurements of how a product performs under various specific conditions with some simple information about how a purchaser intends to use the product, to provide product comparative energy consumption and savings information for his or her particular situation. This kind of meaningful context is largely absent from the one-size-fits-all, traditional physical energy labels placed on most energy-using products today.

Conclusions

Of all the goals a good test procedure can achieve, surely we can agree that producing values reasonably representative of actual usage in the field is among the most important. If test procedure results are unrealistic, mandatory labels provide incorrect information to buyers, voluntary labels imply greater or lesser benefits to buyers of an efficient product than they will actually realize, mandatory standards make the wrong decisions about the extent to which more efficient technologies are cost effective, and utilities assume they will achieve more or less energy from rebating the resulting products than they actually will. This is particularly problematic for utilities, since they rely on their savings estimates in resource planning, and may face electricity shortages and severe financial penalties from their regulators if they do not achieve the energy savings claimed for rebated products.

One truism that emerges from the last 20 years of refinements in appliance design is this: the better the technology, the more behavior matters. In other words, as products have made steady, remarkable gains in technological efficiency, most forms of gross, obvious energy waste have been removed from the system. Likewise, the products have been optimized to perform incredibly well on standardized test procedures, after repeated iterations of laboratory testing, product redesign, and tweaks to the software that controls product operation. Not surprisingly, then, the variation in product functionality and performance introduced by customer behavior ends up being one of the largest remaining contributors to differences in product energy use. We cannot strictly control for variations in user behavior in a laboratory setting, but we can monitor products under a wider range of usage patterns and conditions to understand how they might behave.

In the past, some efficiency test procedures were found to have measured precisely the wrong thing, and those wholesale problems were typically corrected reasonably quickly. Today's test procedures can suffer from a slightly less severe problem – they measure the wrong thing, precisely. They are, with laudable precision and repeatability, measuring things that can be increasingly irrelevant about a product's performance under a narrow set of laboratory conditions rarely found in the real world. This quest for false precision leads, not to the truth, but to overconfidence in the relevance and usefulness of what is being measured.

The history of recent energy efficiency test procedures is filled with reasons for hope that greater realism and representativeness are achievable. In the past, ENERGY STAR measured only the standby power consumption of televisions in determining which models to label. US DOE only measured the power use associated with static test patterns on black and white cathode ray tube televisions, long after color, flat panel, and high definition capability came to televisions. Today, both agencies now utilize an internationally standardized high definition color video test clip and a range of ambient lighting levels interacting with televisions' automatic brightness control circuitry to more reasonably approximate actual viewing conditions, which represents remarkable progress. Likewise, the latest IEC test procedure revision for refrigerators shifts meaningfully toward the goal of testing a broad range of functions and capabilities, leaving to policymakers the option of constructing different "recipes" or duty cycles of those functions to mirror typical usage patterns in their part of the world.[19]

These types of shifts in our approach to test procedures are a healthy adaptation to changing technologies and capabilities in consumer products, and the changing ways in which all of us use those products. While this may introduce less precision and repeatability into measured values, it brings something much more valuable – an unvarnished honesty about what can and can't be known with precision.

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Development of a Communicating Power Supply to Assist in Energy Monitoring and Management

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Abstract

Saving energy in buildings is often hampered by lack of detailed information about what is using energy and how much. The problem is especially acute for the large number of small, energy-using devices that are present in both residential and commercial buildings. Most of these products use a power supply to operate electronic and other internal components. We developed a "communicating power supply" to enable communication of energy information to a building management system or other central entity. A related goal was to assign to each power supply or device a unique identifier, that is, a kind of "electronic UPC" (Universal Product Code) that can be recognized by a building energy management system or other networked entity. The communicating power supply must be flexible enough to transmit data through power line carrier (PLC) or wireless networks, or piggyback on communications capabilities of downstream devices.

We worked with a large manufacturer of power supplies and a large designer of microprocessors to miniaturize these functions onto a single chip which will, ultimately, add very little extra cost or complexity to existing power supply designs. We anticipate that Energy Star and other efficiency endorsement programs will include communications capability in future technical specifications. Our longer-term goal is to add control capabilities to the communicating power supplies.

Background and Project Goals

Saving energy in buildings is often hampered by lack of adequate information about which device is using energy and how much it is using. This problem is especially acute for the large number of smaller energy-using devices that are present in both residential and commercial buildings (e.g., plug loads). A large fraction of these loads are electronics, that is, devices that process information in some manner. In especially efficient homes, plug loads often represent 30% of total electricity use [1] and a similar fraction in commercial buildings [2]. Moreover, the amount of electricity used by plug loads is growing faster than any other load category in both sectors [3]. For example, in the United States, space heating and cooling have now fallen to less than half of total site residential energy use and has been overtaken by appliances, plug loads, and electronics [4]. Most major economies have begun to regulate the efficiencies of the energy-intensive appliances, but hundreds of other products are not expected to be regulated. The growth in these end uses makes their control and management increasingly important.

Today's solutions do a poor job of economically monitoring and controlling plug loads [5]. Furthermore, the in-building consumption is often strongly affected by individual operating practices and are therefore impossible to regulate. Effective energy *management* cannot occur until more information about energy *consumption* is obtained. To date, however, there is no cheap method to know and control the energy consumption of plugged-in devices. Numerous products have recently become available that offer monitoring and control capabilities incorporated in the wall outlet or as an independent power-strip [6]. These partly address the problem but have important drawbacks. First, they must be individually installed and programmed. If the device is moved, or additional devices are plugged in, then the information and control aspects are undermined. Second, many of the products rely on proprietary communications protocols, which leads to incompatibilities and legacy networks. Finally, the products are still relatively expensive so installation of a network connected to all of the devices in a building can easily cost thousands of euros. Thus, they are adequate for short-term or limited operation but not suited for a permanent, scalable, system.

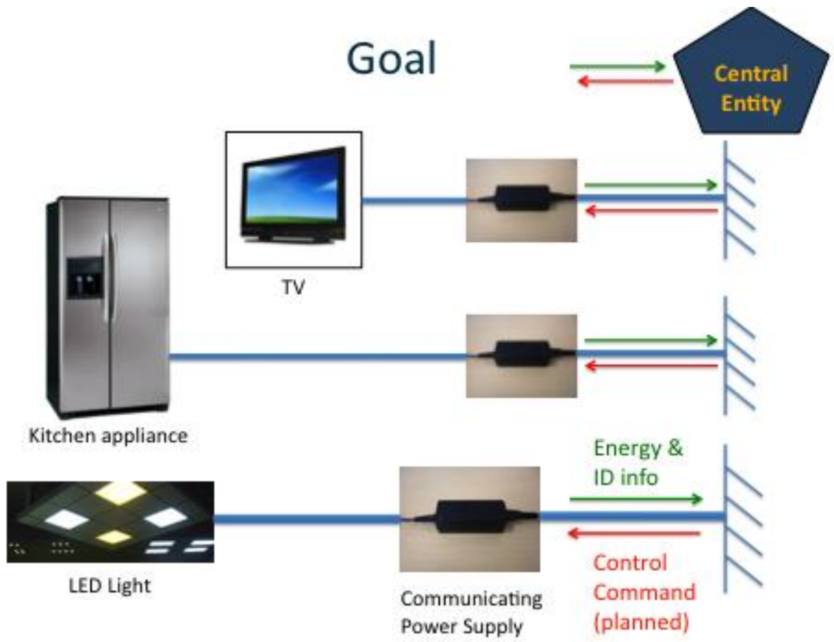


Figure 1. Relationship of the communicating power supply to appliances and the central entity

The goal of this project is to incorporate standard power measurement and reporting capability into power supplies in such a manner so that the incremental cost is very low. The power supply (typically converting AC to DC) is the first destination of electricity flowing to nearly all electronics and in a majority of the small loads. Figure 1 illustrates the general goal of the communicating power supply.

These capabilities will greatly increase the ability to understand energy use in buildings and identify opportunities for savings. These same features may also be exploited in other ways to provide new applications that we cannot predict today, such as to enhance health and safety.

The fundamental building block of this infrastructure is the conventional, switch-mode power supply. Billions of power supplies are manufactured every year for all types of IT equipment, audio and video equipment, mobile phones, and other products. These power supplies are a commodity, costing less than a few euros each for wholesale purchases. The market for these components is extremely competitive, so manufacturers of power supplies are reluctant to add capabilities unless they can be confident that the features are desired by their customers and will pay a higher price.

We collaborated with two companies to develop a technically feasible, economic solution. Power Integrations is a major supplier of high-performance electronic components used in high-voltage power-conversion systems. Its solutions enable compact, energy-efficient AC-DC power supplies for a vast range of electronic products, including TVs, PCs, appliances, smart utility meters and LED lights. We also collaborated with ARM, a supplier of microprocessors in many advanced digital products.

Technical Features of the Communicating Power Supply

The communicating power supply has three features beyond those found in a standard power supply. These are:

- A unique identity for each power supply
- A means for the power supply to measure its energy consumption
- A means for the power supply to communicate that information to the network

Ultimately, the communicating power supply will have a fourth feature: a means of controlling the power use of the device, that is, to switch off the device.

The communicating power supply must participate in a network to deliver information about its activities. This capability requires two features:

- A central entity to receive and process the data
- Standardized protocols for communicating between the communicating power supply and the central entity

A schematic of the network is shown in Figure 2. Product A represents an electronic device without networking capability such as a compact fluorescent light, battery charger, etc. The communicating power supply in this case an external unit, collects product information, controls signals, and energy consumption from Product A. The communicating power supply transmits these data, plus a unique identifier, via power line communication (PLC), and the information is collected in a central entity (that is, a database). Product B represents a networked device, such as a computer, blu-ray, etc. Product B is similar to Product A, with one important difference: the data are transmitted by the networked device via the Ethernet to the central database.

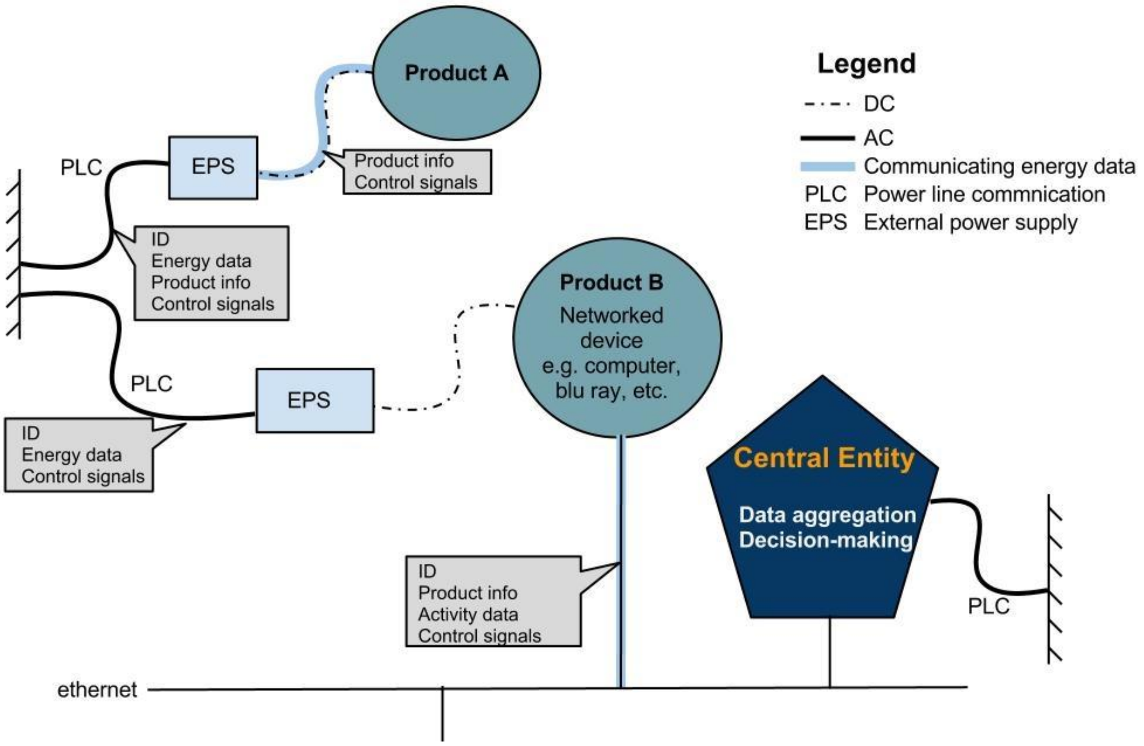


Figure 2. System overview of communicating power supplies

The key aspects of the communicating power supply are described in the following sections.

Unique Identity

Each power supply will need to have a unique identity that no other device will have. In computers today, we use MAC address, a 48 bit identifier, to uniquely identify anything with an Ethernet or Wi-Fi connection. As many more devices are network-connected, there is concern that we may one day run out of MAC addresses because they are inefficiently distributed (i.e., many addresses will never be used, but it is not possible to be sure this is true). As a result the Extended Unique Identifier is new

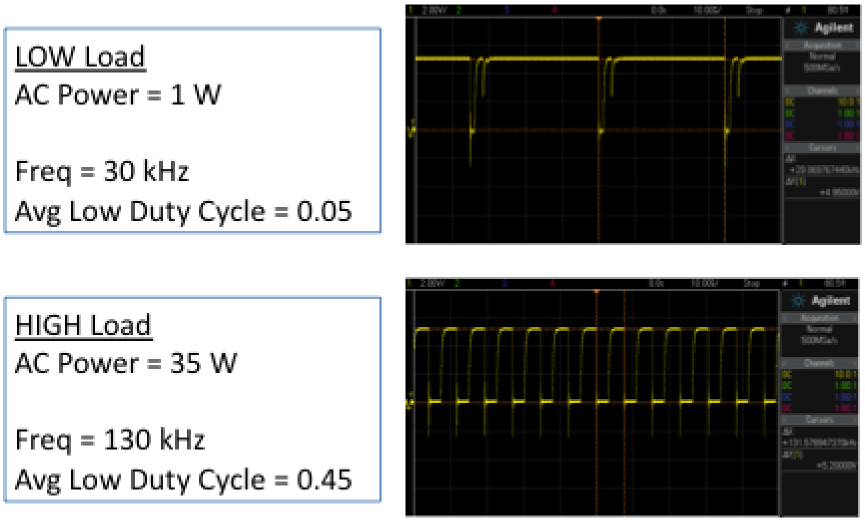
standard in place to replace the MAC address [7], and it is a 64 bit sequence with 2×10^{19} possible addresses. The EUI-64 is the standard unique identifier for the new generation of Internet Protocol networking (IPv6) and the Internet of Things. We have selected the EUI-64 as the unique identifier for this work.

In addition to unique identity, it is useful to have a means to identify the type of device and any other information about that device. The Universal Serial Bus (USB) specification includes a device classification system [8], and this system always includes the use of a few numbers to uniquely identify the vendor, the product (unique for a particular vendor), and the version of the product. It can also include long text strings or binary values to provide information to the user. In the case where only a few numbers are exchanged, the connected system must either be able to interpret these values on its own or connect to a database on the Internet to download the corresponding descriptions. A similar approach is appropriate for communicating power supplies. We propose to use a vendor ID, a vendor-specified device type, a vendor-specified product ID, and a version number. Allowing the vendor to specify these values provides flexibility and allows for innovation. However, if a vendor does not register these values with a central entity, end users and energy management systems will have no way to determine the device type. The alternative is to prescribe a taxonomy of device types rather than allowing for vendor selected values, and this improves device identification at the cost of flexibility. Because understanding the vendor stated device capabilities is critical and must be specified by the vendor, the downside to vendor specified device type seems small.

Measure and Accumulate Data

We developed a system to measure power and energy in a switching power supply using very low-cost components. The switching power supply modulates its switching properties based on the power needed by the load. Measuring these switching properties enables a microprocessor to estimate the load. Figure 3 shows two oscilloscope traces of the switching node of the power supply for low load and high load. The duty cycle (low spent time as a fraction of the total time) varies from 0.05 to 0.45 from low load to maximum load, and the waveform switches value tens or hundreds of thousands of times per second. To cheaply measure this duty cycle, we first take this high speed signal and use an analog filter to determine its average value. The average value is measured using an analog to digital converter, and the resulting digital value is turned into a power value using a look up table with interpolation. Look up tables are very efficient methods for storing non-linear functions on low-cost microprocessor systems.

Low-cost microprocessors often have analog to digital converters with sufficient accuracy to provide better than 1% accuracy over the full range of loads a power supply has to offer. The variability between different power supplies in terms of switching duty cycle versus the load is likely to be a few percent, and the overall accuracy and repeatability will be about 5%. Therefore, even very low-cost analog to digital converters will provide the accuracy needed. The sample rate of this analog signal can be quite low as well, which will further reduce costs. Our implementation has a signal bandwidth of about 1Hz; thus, a sampling rate of only a few times a second will enable the system to fully capture all of the system dynamics.



(Time scale is 10µs/div for both plots.)

Figure 3. Oscilloscope traces demonstrating that a low-cost analog-to-digital monitoring method can achieve acceptable accuracy over a wide range of loads

Communicate via a Network

The communicating power supply must have a network interface to enable communication. Initially, we identified two high-level communication strategies: network communication in the power supply or local communication to another processor in the system that already has a network connection. The second method is preferred to lower system costs if the device is already connected to the network (e.g., an Ethernet or Wi-Fi enabled television). In many cases (e.g., light bulbs), the device will not already be connected to a network, and the lowest cost network connection that provides the required performance is desired. We previously surveyed a variety of network connections possible, and low-cost wireless connections such as Zigbee, Z-wave, or 6LoWPAN are the best options. Power line carrier communication requires not only expensive chips but also expensive passive components. The chips and passives required for Zigbee of 6LoWPAN can be purchased for under one euro in moderate volumes, and it seems likely these chips will decrease in cost further as volumes increase. Z-wave chips are more expensive but have enhanced interoperability. We do not want to pick a “winner” technology in this space, but it is clear that the low-cost wireless options have a significant advantage in terms of cost and implementation complexity.

Results and Future Work

Our goal was to demonstrate a proof of concept, that is, a power supply that can measure power use, store its identity, and then communicate this information to a central entity. As indicated, this is a hardware, software, and communications problem, extending beyond the power supply itself.

We successfully created a prototype communicating power supply (see Figure 4). This has already undergone one generation of miniaturization. Ultimately, the components will need to be integrated into a single chip (or two) so that it does not enlarge the form factor of existing power supplies.

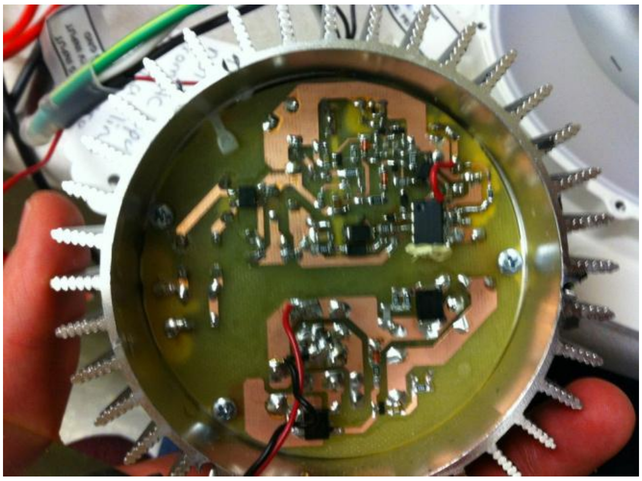


Figure 4. Second-generation prototype of communicating power supply

We also created a network consisting of three devices, each with a communicating power supply. These products report identity and energy information over a wireless network (based on IEEE 802.15.4, the same wireless standard as Zigbee [9] and 6LoWPAN [10] . Finally, we created a basic energy dashboard that can display energy information collected by the system. This dashboard offers sufficient features to demonstrate functionality of the whole system. The data will be stored to a database, and users will be able to view data at will.

The same hardware and network can, in principle, be used in reverse to send control messages from the central entity to specific equipment. This will enable the devices to be remotely switched on and off. Remote control will be the subject of future work.

A communicating power supply will cost more than conventional power supplies. Our goal is to make the incremental cost very small. The measurement feature will cost less than €0.10 when mass produced. For appliances already equipped with communications capability, the communicating power supply could piggy-back; this will lower the cost since communications is the most expensive feature. However, external incentives will still be needed to encourage manufacturers to add this feature. Voluntary programs, such as Energy Star, could easily make communications part of their specifications. These programs could assure a market and encourage economies of scale.

Communicating power supplies, and the ecosystem in which they operate, will permit much more detailed understanding of electricity consumption. This offers the potential for reducing energy consumption of products whose services are not required at that specific time without the active involvement of the occupants.

Acknowledgments

This work was supported by the California Energy Commission's Public Interest Energy Research program and by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy, under Contract No. DE-AC02-05CH11231.

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Wireless Communication in Smart Grid Home Area Networks: A Survey

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Abstract

This paper presents a survey on the most promising wireless communications candidates to be used as part of a smart grid home area network. Particular attention is devoted to the systems' physical layer due to its implications on the coverage area and on the provided service throughput and latency. Different cellular networks (GSM/GPRS and UMTS) and wireless data networks (Bluetooth, ZigBee, Wi-Fi and WIMAX) are analyzed. Moreover, two very simple smart energy applications were designed and implemented in order to validate the selected wireless communication solutions. The first aims to accomplish vehicle to grid (V2G) energy exchange, thus allowing efficient energy management on the smart grid. The communications between the electric vehicle and the infrastructure is performed via WLAN at home and using SMS messages otherwise. The second application implements a home lighting automation process using the ZigBee/IEEE 802.15.4 protocol.

INTRODUCTION

The "Smart grid" concept intends to improve the efficiency, reliability, and sustainability of electrical energy production and distribution using the energy consumption information on the consumer side and utility pricing [1]. Wireless technologies are promising candidates to perform that crucial, last mile, exchange of information because they inherently provide terminal mobility, low installation cost, rapid deployment and extended coverage. The accessibility to multiple radio access technology standards such as cellular networks (2G; 3G and 4G), IEEE 802.11 a/b/g/n wireless LAN, WiMAX and ZigBee supported on IEEE 802.15.4 provides the mentioned benefits and redundancy and therefore a clear advantage over wired technologies.

Among the loads present at home, the EV is perhaps the most promising candidate to optimize residential energy consumption due to the involved high power value, its energy storage capability and to its potential bidirectional transmission of electricity. Indeed, EV batteries can serve as an energy storage unit that can return energy back to the grid when parked, accomplishing the vehicle to grid (V2G) concept. Consequently, the accurate identification, on a given area, of the vehicle's location, parking status, and, mainly, its storage capacity and state of charge (SOC) can be used to design an energy efficiency strategy. When parked at home the EV can use available wireless networks to communicate with the smart grid. Home area network (HAN) communications typically require a relatively low data transfer rate (< 1 Mbps), high reliability, low latency, low power consumption, secure communication and a medium range coverage area [2].

Subsequent sections describe the radio interface of the most important cellular systems used nowadays, namely the GSM/GPRS, EDGE and UMTS systems. This description also includes wireless systems like ZigBee, Wi-Fi and WiMAX. Finally, an SMS-based application was developed to support the information exchange between EVs and the electric grid. The implemented communication solution used to send and receive data information is fully explained.

WIRELESS COMMUNICATION SYSTEMS

Wireless communications systems are natural candidates to be used in smart grids and particularly in a home area network. The lack of wired connections enables equipment mobility, offers low-cost solutions and provides flexibility in the communications network configuration, aspects that are of particular value. Among the multiple wireless technologies that were examined, particular attention was given to mobile cellular systems (e.g. GSM and UMTS) and to wireless networks such as WiMAX, Wi-Fi and ZigBee.

Global System for Mobile Communications (GSM) - Cellular System

Cellular systems topology consists in multiple overlapping cells that provide coverage, obtained from relatively low power transmitters located on base stations. GSM is a second generation (2G) mobile system based on digital technology, designed and optimized to support the voice service.

GSM frequency bands or frequency ranges are the cellular frequencies designated worldwide by the International Telecommunication Union (ITU) for the operation of GSM mobile phones. In Europe most used frequencies to support GSM/GPRS are the 900 and 1800 MHz bands. However, according to the Third Generation Partnership Project (3GPP), there are fourteen licensed frequency bands defined to this system [3]. The available spectrum is divided into radio carriers, each having a bandwidth of 200 kHz. One or more carrier frequencies are then assigned to each base station. Each of these carrier frequencies is then divided in time, using a time division multiple access (TDMA) scheme, into eight distinct time slots which will be used to support speech and data channels. One time slot is used for transmission by the mobile and another one for reception. They are separated in time so that the mobile unit does not receive and transmit at the same time (as represented in Fig. 1).

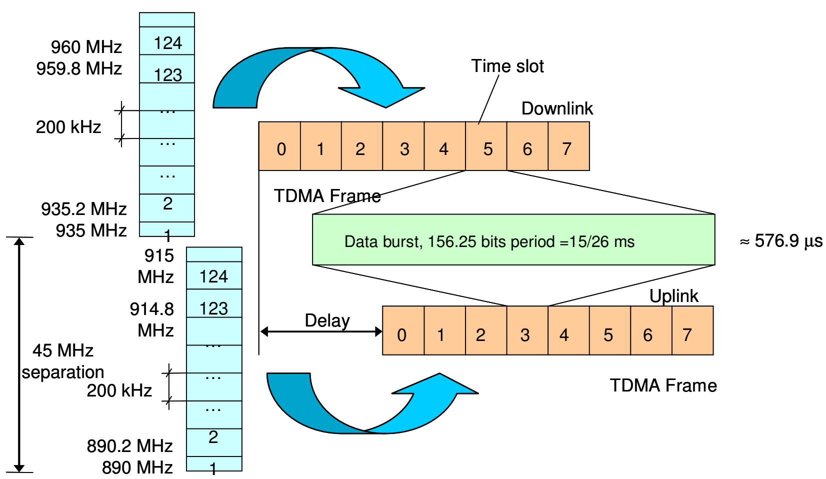

Fig. 1 - GSM 900 carriers and TDMA frame structure. (Adapted from [4])

Enhanced Data Rates for GSM Evolution (EDGE) and General Packet Radio Service (GPRS)

Enhanced Data for GSM Evolution (EDGE) is a GSM evolution that provides third generation (3G) capabilities in the existing frequency bands. EDGE enables services like web browsing, email, multimedia and video conferencing to be accessible from its mobile terminals.

The GSM standard provides data services with bit transfer rates up to 14.4 kbps for circuit-switched data and up to 22.8 kbps for packet data (per time slot). Thus higher bit rates can only be achieved with multislot operation. The General Packet Radio Service (GPRS) provides bit transfer rates up to 171.2 kbps depending on the radio link quality, the number of other users sharing the service and the user-negotiated quality of service (QoS) [4, 5].

Both GSM and GPRS systems are based on the Gaussian minimum shift keying (GMSK) modulation technique that has a spectral efficiency of 1.35 bps/Hz, which correspond to an aggregate data rate per carrier of 270.833 kbps. The core of the EDGE concept includes the introduction of a new phase shift keying modulation scheme 8-PSK, which allows data to be sent at speeds up to 384 kbps [5]. This data rate increase is obtained from the usage of 8-PSK modulation technique that has a 3 bit per symbol efficiency. Note that the symbol rate for both modulations is 270.8(3) ksymb/s, leading to gross bit rates per time slot of 22.8 kbps and 59.2 kbps for GMSK and 8-PSK respectively.

Universal Mobile Telecommunications System (UMTS)

UMTS is a third generation cellular technology designed to provide mobile personal communications (with anyone, anywhere and anytime) with transmission rates up to 2 Mbps according to the environments of use, support universal roaming and wideband multimedia services offer. The UMTS system is based on a set of basic requirements that includes: a high spectral efficiency, a large traffic capacity, the support of different services and applications, indoor and outdoor coverage, the use of small, light, low price and high autonomy terminals, high quality service, and the establishment of secure communications. The system provides a broad range of services to a large number of users. The services provided by the system include the telephony voice service, new multimedia and Internet services, which should be available from a variety of terminals and platforms.

The first 3GPP version of the UMTS, known as Release 99, is an evolution of the GSM/GPRS network architecture, the main difference for these generations is the radio access network. The original base station system (BSS) was replaced by a new entity named UMTS terrestrial radio access network (UTRAN), where the radio network controller (RNC) and node B, replace the base station controller (BSC) and the base transceiver station (BTS), respectively. Subsequently, a second version was specified for UMTS, the 3GPP release 4, that was appropriated for new cellular network operators that initiate 3G services provision without a 2G network. In this version the main change occurs in the core network where the MSC is separated into two new network elements, the Media Gateway (MGW) and MSC server. The aim of these new elements is to separate the control/signalling tasks and transmission/support in order to use a single routing and transmission technology, making possible the support of services with different QoS requirements.

High Speed Downlink Packet Access (HSDPA)

HSDPA introduces a set of new features in the UTRAN (3GPP R5) that when combined enable a significant increase in data transmission rates up to a maximum of 14.4 Mbps. HSDPA creates a high-speed DSCH (HS-DSCH) by replacing the variable spreading factor (VSF) and fast power control with adaptive modulation and coding (AMC), short packet size, multi-code operation, and fast hybrid automatic repeat request (HARQ). A higher performance is obtained from the ability to share the HS-PDSCH channel that is dynamically partitioned by the HSDPA users, up to a maximum of 15 parallel in each cell. The channelization channels can be assigned to a single user or shared by multiple users in each transmission time interval (TTI). The observed reduction on the packet duration time, as it decreases from 10 or 20 ms (UMTS R99/R4) to a fixed duration of 2 ms (HSPDA), allows faster adaptation to changes in traffic conditions. Moreover, when the radio channel conditions are quite good HSDPA promotes the 16-QAM modulation technique usage. The 16-QAM modulation technique allows faster transmission rates than traditional quaternary phase shift keying QPSK modulation technique used for UMTS R99/R4 due to its increased spectral efficiency.

High Speed Unlink Packet Access (HSUPA)

HSUPA introduces a set of new features in the UTRAN (3GPP R6) that improves uplink performance (compared to R99 UMTS) and provides a higher throughput/data rates (up to 5.8 Mbps), superior capacity and reduced latency. The enhanced features in the uplink comprise several improvements, similar to those performed by the HSDPA, including multi-code transmission, short transmission time interval (TTI = 2 ms), fast scheduling and fast HARQ.

IEEE 802.11 protocol Wi-Fi

A wireless local area network (WLAN) is a wireless communication system that allows notebooks, computers, PDAs and tablets PC to access and share data, internet access or other network resources in the same way as for wired networks. Its main advantages comprise terminal mobility, short term usage, speed of deployment and scalability. There are also some disadvantages such as power consumption, low safety levels and operating frequencies that differ from country to country.

The IEEE 802.11 protocol usually referred as wireless fidelity, or simply Wi-Fi, is a network access technology that provides connectivity between wireless stations know as access points (APs) and wired networking infrastructures. The different versions of IEEE 802.11, presented in table 1, include:

- 802.11b - is the older version, transmits in the 2.4 GHz band and supports transmission rate of 11 Mbps and uses complementary code keying (CCK) encoding;
- 802.11g - also transmits in the 2.4 GHz band, but supports maximum speeds of 54 Mbps, the usage of orthogonal frequency division multiplexing (OFDM) increases the efficiency;
- 802.11a - same as 802.11g, but it uses channels in the 5 GHz band;
- 802.11n - introduces multiple input multiple output MIMO; a wider channel bandwidth 40 MHz as an option and considers beam forming and diversity in the antennas technology.

Table 1 - Comparison of Wi-Fi variants [5]

Parameters	802.11a	802.11b	802.11g	802.11n
Approval date	July 1999	July 1999	June 2003	October 2009
Frequency band	5 GHz	2.4 GHz	5 GHz	2.4 / 5 GHz
Max data rate	up to 54 Mbps	11 Mbps	up to 54 Mbps	up to 300 Mbps
Modulation	OFDM	CCK, PBCC, DSSS	OFDM, PBCC, CCK, DSSS	OFDM, CCK or DSSS

Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is broadband wireless access (BWA) technology, based on IEEE 802.16 standard created with the aim of providing wireless access to the Internet with the following characteristics: large geographical coverage area; huge number of simultaneous users accessing the network; high transmission rate and low cost. It fits a wide range of applications and environments: data, voice and multimedia fixed and mobile, licensed and unlicensed. The WiMAX original standard specified a frequency range of 10-66 GHz with a theoretical maximum bandwidth of 120 Mbps and maximum transmission range of 50 km [6]. It was designed to bring end-user wireless Internet without the expense and inconvenience of wiring or the distance limitations of digital subscriber line (DSL).

WiMAX physical layer is based on OFDM (in 802.16d) or OFDMA (in 802.16e). This guarantees two advantages: firstly the robustness against the multipath spatial multiplexing, i.e., transmitting independent streams performed in parallel for different antennas, and secondly the flexibility to include algorithms and techniques such as adaptive modulation and coding techniques and efficient multiple access techniques.

The signal is composed by 256 carriers (fixed) or 128-2048 carriers (mobile) depending on the bandwidth (restricted to 20 MHz or less and an integer multiple of 1.25 MHz, 1.5 MHz, or 1.75 MHz). From these carriers only 3/4 are actually used for data being remainders used as guard bands and as pilots. The pilot carrier always uses binary phase shift keying (BPSK) modulation and data modulation uses BPSK, QPSK, 16-QAM or 64-QAM depending on channel conditions. At closer ranges WiMAX can use M-ary QAM and support throughputs higher than 50 Mbps. At longer ranges, lower-order modulations with lower-rate coding must be used, hence decreasing the data throughput [6]. WiMAX can use both time division duplexing (TDD) and frequency division duplexing (FDD). The main differences between WiMAX variants are presented in table 2.

WiMAX is supported by the WiMAX Forum, whose primary mission is to ensure compatibility and interoperability between devices based on the IEEE 802.16 and is mainly composed of chipsets equipment manufacturers. The WiMAX Forum is the equivalent of the Wi-Fi Alliance, responsible for the great development and success of Wi-Fi all over the world.

Table 2 - Comparison of WIMAX variants [5]

Parameters	802.16	802.16a/d	802.16e
Approval date	Dec 2001	Jan. 2003/June 2004	End of 2005
Spectrum	10 to 66 GHz	2 to 11 GHz	2 to 6 GHz
Max data rate	134 Mbps (64-QAM, 28 MHz Ch)	75 Mbps (20 MHz Ch)	15 Mbps (5 MHz Ch)
Modulation	QPSK, QAM	BPSK, QPSK, QAM, OFDM	BPSK,QPSK, QAM, OFDM
Mobility	Fixed	Fixed and portable	Mobility, roaming

Bluetooth / IEEE 802.15.1

The Bluetooth protocol includes a specification for wireless personal area networks (PAN), developed by the Bluetooth Special Interest Group with the aim of connecting devices via a radio link of small range. Although operating on the same 2.4 GHz (2.4–2.5 GHz band) as Wi-Fi systems, the industrial, scientific and medical (ISM) band uses a different multiplex scheme, allowing their coexistence. The protocol allows data transfer at a speed of 1 Mbps with distances that can range from 1 m to 100 m. The fact that it is a standard protocol designed for low power and short range has allowed its dissemination into various types of devices.

ZigBee / IEEE 802.15.4

ZigBee is a low-cost, low-power, secure and reliable wireless mesh network standard appropriate for applications such as home automation (lighting control systems, intruder alarms), energy management, automatic meter reading systems, environmental and agricultural monitoring, video audio remote controls and personal health care (e.g. heart rate monitoring). The term ZigBee refers to a set of protocols that enable wireless communications between devices and is intended to replace the proliferation of cables and individual remote controls. One of the ZigBee protocol’s major advantages is its low power consumption, allowing small batteries with a long life cycle, ideal to install and forget purposes. Another ZigBee characteristic is its potential widespread implementation on a huge number of wireless devices. ZigBee also has high throughput and extremely low latency, making it suitable for real time applications. ZigBee implements a fully reliable “hand shake” protocol and three network topologies possibilities: star, mesh and cluster-tree; allowing up to 65535 device network supported in a up to 64 bit IEEE address. ZigBee includes two layers of the OSI model, the Application Layer (APL) and the Network Layer (NWL) that operate on top of the IEEE 802.15.4 PHY and MAC layers.

There are three types of devices in a ZigBee network: a coordinator (single device on the network) that creates and configures the network, acts as an IEEE 802.15.4 PAN coordinator. However, once the network is formed it is a Full Functional Device (FFD) that implements the full protocol stack and makes the interconnection between other networks. A router that is also a FFD implementing the full protocol stack, will forward the packets on the network, relaying data. Finally, a ZigBee end node that can only transmit data packets to the network without additional functionality and does not participate in routing. ZigBee end devices are Reduced Function Device (RFD) that implements a reduced subset of the protocol stack. This equipment (typically a mobile device) is where one wishes to obtain low energy consumption, operating at a low duty cycle.

Physical Layer

The physical layer of IEEE 802.15.4 is responsible for the following tasks: activation and deactivation of the radio transceiver; energy detection; link quality indication; clear channel assessment and channel frequency selection. IEEE 802.15.4 operates in three ISM unlicensed bands: 2.4 GHz (global), 915 MHz (Americas), and 868 MHz (Europe) [8]. As Fig. 2 shows, there is a single channel between 868 and 868.6 MHz (numbered 0), 10 channels between 902 and 928 MHz (numbered 1-10), and 16 channels between 2.4 and 2.4835 GHz (numbered 11-26).

Each channel in the 2.4 GHz band provides a raw data transfer rate of 250 kbps. The channel width is 2 MHz with 5 MHz of channel spacing in a way that allows interoperability with IEEE 802.11b. Direct sequence spread spectrum (DSSS) is used in conjunction with offset quadrature phase-shift modulation (OQPSK). On the other hand, channels in the 915 MHz band use the BPSK modulation technique that results in a lower data transfer rate (40 kbps). The receiver sensitivity should be larger than -92 dBm for channels in the 915 MHz band and larger than -85 dBm for channels in the 2.4 GHz band.

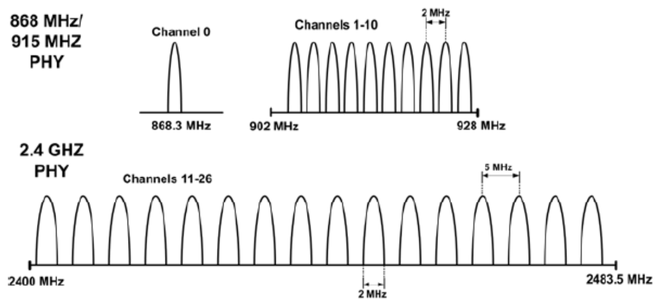

Fig. 2 – IEEE 802.15.4 operating frequencies and bands [8]

Medium Access Control (MAC) Sub-layer

The MAC data service is responsible for the transmission and reception of MAC protocol data units across the PHY data service. The features of the MAC sublayer are beacon management, channel access, GTS management, frame validation, acknowledged frame delivery, association and disassociation.

The MAC protocol supports two operational modes (as shown in Fig. 3). In the <u>non-beacon enable mode,</u> a standard ALOHA mechanism is used to rule the medium access and neither beacons nor superframes are used when the coordinator selects this mode. In the <u>beacon enable mode</u>, the coordinator periodically sends beacons to other network devices in order to synchronize nodes. The beacon defines the start of a superframe used to control channel access. The proposed frame structure assures dedicated bandwidth and low latency to 16 equal width time slots. Medium access is ruled by slotted carrier sense medium access with collision avoidance (CSMA/CA).

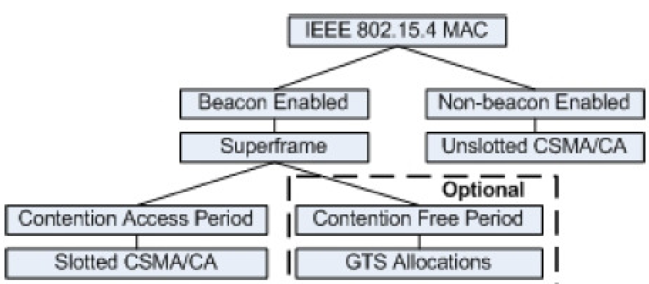

Fig. 3 – IEEE 802.15.4 operational modes [8]

V2G communications based on SMS

In the scope of this paper, efforts have been made in the V2G communications implementation [9]. The used onboard unit consists in a microprocessor, a GPS module and a GSM/GPRS module with a SIM card. The implemented test bed includes the LinkSprite GSM/GPRS module named SM5100B [10], a miniature single-side board, quad-band GSM 850/EGSM 900/DCS 1800/PCS 1900.

V2G communication required information

The considered information includes the following fields [11]:

- Vehicle/onboard unit identification; (using SIM module ID)
- Vehicle location; (using GPS and the GSM Cell ID)
- Vehicle speed; (using GPS)
- Charging station(s) location; (GPS)
- Driving destination;
- Driving cycle history; (supported on a high rate communication e.g. IEEE 802.11.b/g)
- Power demand profile;
- Power supplied or charged by the sources;
- Battery state of charge (SoC);
- Charging/discharging time and current data;
- Power electronics module parameters.

The Short Message Service (SMS)

The SMS is one of the most successful telecommunication services in terms of number of users and cost-effectiveness. SMS is supported by cellular networks such as GSM and UMTS. Initially the SMS specifications were written into the ETSI scope and included the service definition, network architecture, protocols and functionalities. Later, an innovative concept, the 3GPP, was created in order to define a radio access technology for a future generation cellular system that was intended to be global. The success of GSM system and its upgrades that include the GPRS and EDGE have led to the preservation of the GSM as a part of the future system's core.

The SMS provides short text messages transfer, in a connectionless mode, supported by the cellular networks radio resources. SMS offers a mean of sending messages, up to 160 characters (7 bit coding), to and from a mobile phone, fax machine and/or IP address [12]. SMS is a store and forward service that uses a Short Message Service Center (SMSC), to relay the messages from sender to the appropriate recipient. The cellular network, checks if the originating mobile station (MS) is allowed to use the short message service, by querying the Home Location Register (HLR) database. If the mobile is allowed to send the message, then MSC routes the short text message to the SMSC which must then direct it to the appropriate mobile device. The SMSC sends a SMS Request to the HLR in order to find the destination. The HLR responds to the query by sending the serving MSCs address of the terminating MS. The message in a Short Message Delivery Point-to-Point format is transferred from the SMSC to the serving system. Once the location of the receiver MS is found, the MSC further queries its Visitor Location Register (VLR) database, the system pages the recipient device, if it responds, the short message is delivered by the serving cell BSS. The final step in this protocol is the verification that the message was properly received [13].

The implemented data communication system

The implemented solution in this paper uses the well known AT commands in order to configure the message format, send a message and read, write and delete SMS messages. The 3GPP TS 27.005, (ETSI 07.05) specifies AT commands and interface protocols for control of SMS functions within a typical mobile cellular unit (e.g. SM5100B modem), from a remote terminal via an asynchronous interface [14].

In order to send SMS messages (V2G information), it is necessary to place a valid SIM card on the modem external socket that is directly connected with the Arduino Uno. The Arduino Uno presented in figure 4 is a microcontroller board based on the ATmega328. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz crystal oscillator, and a USB connection. The serial communication between the Arduino Uno board and the SM5100B modem is established using TTL serial data.

Fig 4 - Arduino plus the GSM/GPRS shield containing the SM5100B modem

After that it is necessary to verify if the modem is waiting for a Personal Identification Number (PIN) using for example the AT command "AT+CPIN?". In order to overcome this step it is advisable to disable the PIN usage before place the SIM card on the modem. In order to operate in text mode it is necessary to set the cellular modem for that purpose using the command “AT+CMGF”. To send a SMS message, the microprocessor should write the following command: AT+CMGS= "+35196xxxxxxx" <ENTER>. If the modem responds positively the message text can be inserted reporting the available EV information following a proprietary protocol. The message is sent when the <CTRL><Z> is inserted.

In addition, it is necessary to configure the communication link in the opposite direction (grid to the vehicle). The EV receives information and/or commands also by SMSs. Thus, it is necessary to know how the newly arrived SMS messages should be handled by the modem. The command AT +CNMI is used to specify that the newly arrived SMS messages forward directly to the serial port disabling that way its storage in the SIM card. The information available in the serial port is handled by the micro processor that decodes the messages and/or commands and performs the required actions.

Basic home automation system based on IEEE 802.15.4 communication

Home lighting and air conditioning are two very important systems to our well-being. However, they must be redesigned in order to increase energy efficiency. Nowadays home lighting systems use so far non efficient incandescent and fluorescent technologies instead of light emitting diode (LED) illumination. In addition, natural sunlight is not properly used in conjunction with artificial light resulting in excessive illumination in some daylight hours. Thus, future systems should be able of dimming the artificial light smartly based on light sensor information. Moreover, often lighting systems remain turned on unintentionally, even if nobody is in a particular room or office leading to severe energy inefficiencies.

In order to cope with the mentioned problems a simple prototype was developed in order to centrally switch on/off a particular room illumination based on human presence. It also monitors room temperature. The proposed solution is based on two different models modules: the sensor and the actuator. The communication between them (sensor and actuator) is performed using low power RF modules MRF24J40MA from Microchip [15]. The MRF24J40 is a 2.4 GHz transceiver that supports ZigBee and MiWi protocols over IEEE 802.15.4. However other private protocols can be used.

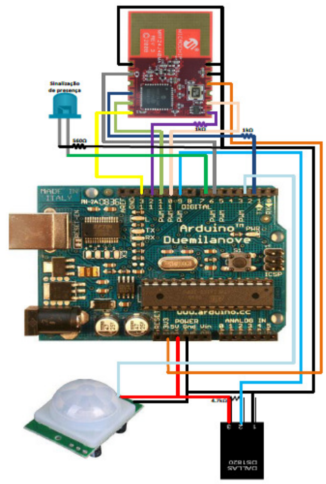

Fig 5 - Arduino plus the Microchip ZigBee MRF24J40 transceiver and sensors

The sensor module presented in Figure 5 has a motion sensor attached that must be installed on top of the room and one or more temperature sensors. The collected information (motion and temperature) is sent to the actuator module to perform both lighting system management and room temperature monitoring.

The microcontroller of sensor module was programmed as follows: every ten seconds, the room temperature is measured by each individual sensor being the obtained values transmitted to the actuator module. Thereafter, it stores the received temperature values in a database that can be accessed by Internet to monitoring purposes. The developed system does not implement any form of control over the air conditioning system, however from performed tests it is expected that future implementations integrate that functionality.

With a correct position of the motion sensor is possible to identify when people leave/came a/to a particular room. Thus, if the system identifies an empty room with the lights on it overrides manual mode and switch off the room lightning system. However, every time a movement is detected inside a likely empty room the module instantaneously switch on the lighting system. It is possible to know in real time what is happening in each module using an USB port to read the serial communications data. These readings can be accomplished using either the Arduino serial port or the Internet.

Conclusions

This paper presents a survey on wireless communication systems in order to investigate their feasibility for smart grid home area networks. Particular attention was devoted to cellular systems such as GSM/GPRS, EDGE and UMTS. Cellular systems offer ubiquitous coverage over existing network operators' infrastructure and low latency; however, the provision of data communication between smart entities and data aggregators is costly. This is because the network radio resources are shared with the mobile network users without QoS and availability guaranties. Moreover, offered QoS is directly related with the received radio signal strength and quality precluding high performance services usage in cells' boundaries.

The simple message service (SMS) common to all cellular systems is, however, very useful to support non-critical applications with low requirements such as home automation networks and alarms. Internet based services are possible using GPRS; EDGE and UMTS networks. Cellular systems coverage area extends the strictly HAN and is also available in neighborhood area network (NAN).

Wireless sensor networks are by nature skilled to interchange information between metering sensors and a data aggregator entity in a HAN scenario. Among the existent solutions ZigBee technology is probably the most suited for these application due to its inherent low power consumption, low cost of deployment, relatively large communication range (near to 100 m) and technical reliability supported on the IEEE 802.15.4 standardized protocol. Nevertheless, ZigBee operation at the 2.4 GHz frequency band is subject of interference from other radio systems and wireless networks that use the same part of the ISM band spectrum. The coordinated channels allocation on both network ZigBee and IEEE 802.11.g is complex but possible and simultaneous operation of both networks was considered in standardization.

The communication between EVs and the electrical grid, crucial to a reliable V2G implementation was analyzed in this paper. The EV location, speed, destination and parking status in conjunction with the batteries SoC is sent to a data aggregator entity using SMS supported by all the cellular networks. The retrieved data is then used to forecast the vehicle capacity to provide energy to the grid when parked. The EV might also furnish important statistics data such as the driving cycle history and the power demand profile using Wi-Fi when located on the home premises. The presented solution allows the V2G concept implementation by means of a more efficient energy management technique implementation on the smart grid.

Acknowledgments

This work was supported in part by Portuguese FCT—Science and Technology Foundation, through the project grants MIT/SET/0018/2009, PTDC/EEA-EEL/121284/2010, and PEst- C/EEI/UI0308/2011.

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Energy efficiency in Inovcity Évora

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Abstract

EDP Distribuição, the Portuguese Distribution System Operator (DSO) for electricity, has been progressively developing a solution for the implementation of a smarter grid – the Inovgrid project. The municipality of Évora, in Portugal, was chosen as the ideal place to implement, measure, evaluate and enhance the Inovgrid solution – this specific implementation of the project is called the Inovcity.

The main objectives of Inovcity were (i) to validate the technical solution and its associated installation and operation processes, (ii) to validate the business case of the solution, evaluating its main costs and benefits and (iii) to promote energy efficiency and rational use of energy.

This paper intends to describe the energy efficiency results within the Inovcity, while giving an integrated view of the project that made possible those achievements and the importance of energy efficiency in the business case for the development of smart grids. Thus, the paper addresses the strategy of EDP for the smart grids, describes the main characteristics of the solution implemented in the Inovcity, highlights the most relevant benefits supporting the business case of such a solution, details the energy efficiency results obtained, presents the international cooperation context of the project and draws some conclusions focused on the results achieved and the next steps of the work.

EDP's smart grids strategy

Inovgrid is EDP's umbrella project for smart grids. With this project, EDP Distribuição seeks to transform its distribution grid and position it as a robust answer to the main challenges ahead: the need for increased energy efficiency; the pressure to reduce costs and to increase operational efficiency; the commitment to keep and improve quality of service; the integration of a large share of dispersed renewables generation; the management of electric vehicles charging; the need to empower customers and to promote the development of new energy services. Beyond the technological aspects, project InovGrid is providing EDP Distribuição with the know-how and experience that will enable a smooth transition of the organization to the smart grid paradigm.

Inovgrid is a distinctive project in the European landscape because it combines a reasonable size (in its most known implementation in the city and region of Évora, the Inovcity) in terms of the number of customers reached, with a strong focus on the smart grid vision (as opposed to projects purely smart meter oriented). After compiling a catalogue of all European Smart Grid projects, the Joint Research Centre (JRC) of the European Commission (EC) has recognized the unique positioning of project Inovgrid by choosing it as the single case study on which to base the development of its "Guidelines for Conducting a Cost-Benefit Analysis of Smart Grid Projects" [1].

EDP believes that smart grids have the potential to help Distribution System Operators address the technical challenges posed by new technologies, such as dispersed generation and electric vehicles, while contributing to the ever-present challenges of efficiency and quality of service. The evolution towards a smarter grid is touching a number of different areas at EDP Distribuição, supporting the various components of the solution presented in figure 1. With project Inovgrid, we seek an integrated approach to this change process.

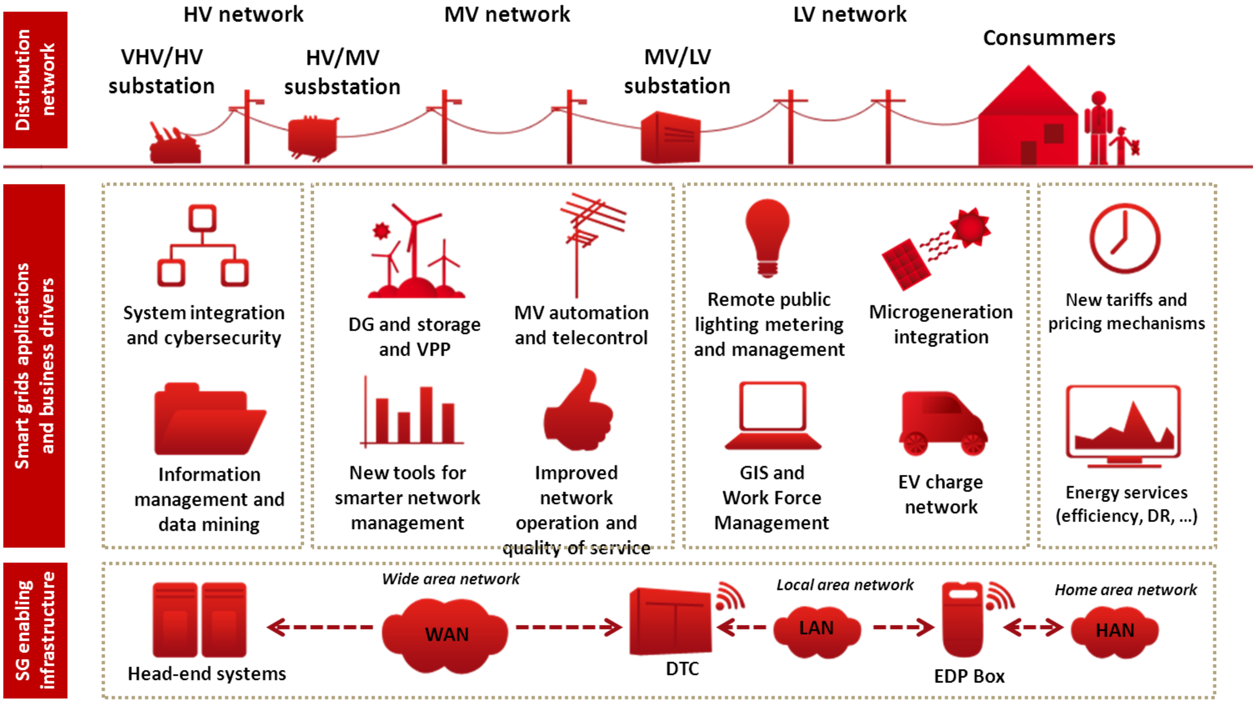

Figure 1: Smart grid components

Évora Inovcity

The main development of project Inovgrid so far has been the implementation of a Smart Grid infrastructure in the Portuguese municipality of Évora, called the Inovcity [2]. The infrastructure spans the entire municipality, around 1.300 km^2, reaching around 31.000 electricity customers with an annual consumption of approximately 270 GWh, and encompasses 340 secondary substations. Additionally, there are 140 medium voltage customers with an annual consumption of 110 GWh. In this non-residential segment, industrial activities account for 57% of electricity use, while services account for 34% and agriculture and other activities for the remaining 9%.

Évora Inovcity is a living lab for the Inovgrid project, with a set of different initiatives in several areas of the electricity grid and involving multiple players of the local community. The field implementation of the project took place during 2010 and 2011. Tuning of the solution, mainly in what concerns communications, systems and processes occurred essentially in 2011/2012.

In order to make visible and promote the Inovcity, EDP built a project showroom in one of the main squares of the city (Praça do Sertório), and ensured that several points of interest could be found in that same square, making it easier to explain and to understand, in short organized visits, the relevant characteristics of the solution. Thus, one can find, within a very short area, the following demo-sites as depicted in figure 2:

- the Inovcity showroom, presenting a demo-station with the main physical components of the implemented solution, several video presentations about smart grids and the Inovcity, a set of devices for in-home energy monitoring and control;
- the Vinyl Café, equipped with an EDP Box and energy control devices, presenting a real use case of the interaction with the costumer;
- the City Hall, where energy consumption and own production are presented, together with other information, in a totem at the entrance of the building;
- efficient public lighting system, based on LED luminaries with advanced sensing and remote control;

- electric vehicle public charging station;
- underground automated secondary substation, equipped with Distribution Transformer Controller (DTC) for monitoring and control, and EDP Boxes for metering the power transformers; this dual transformer secondary substation includes also the automation devices and a multiple sensors system for ambient and transformer oil temperature, humidity, melted fuse in feeders, door open.

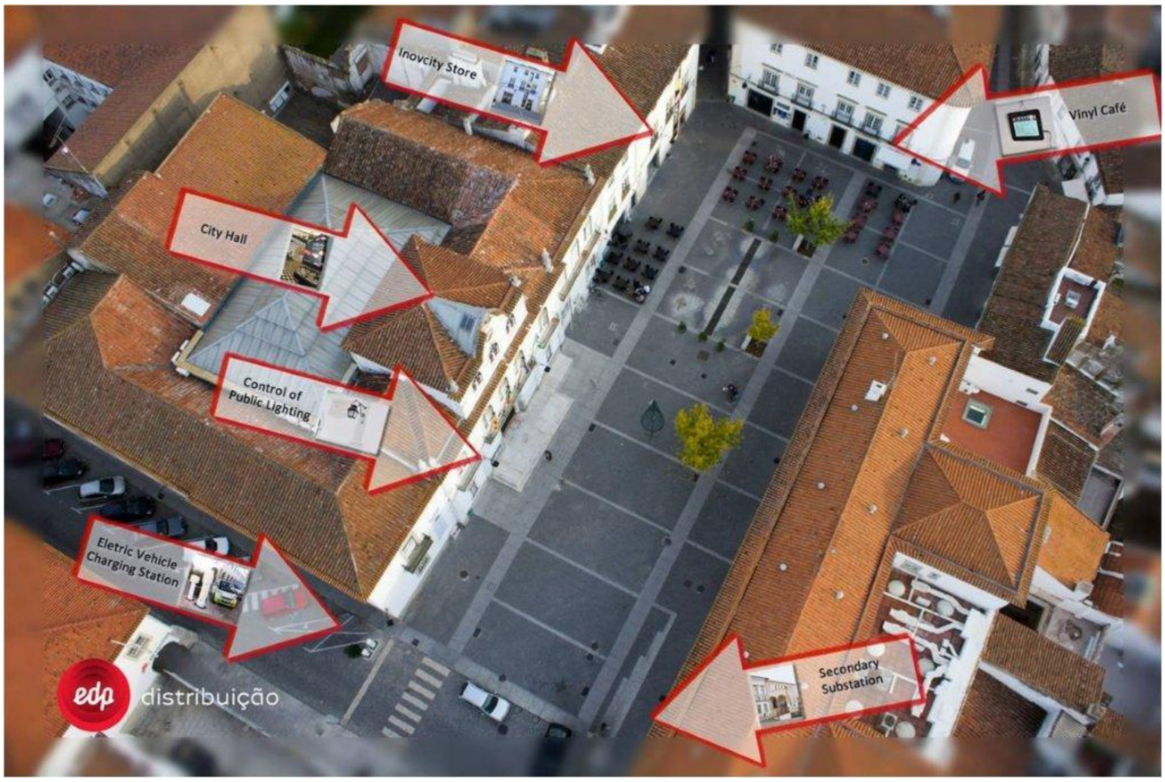

Figure 2: Demo sites in the Inovcity (Sertório square, Évora)

From a technical perspective, the architecture of the system deployed in Évora includes the following components:

- EDP Boxes (EB), installed in all low voltage customers, offering advanced smart meter functionalities, such as real time readings on demand, load diagrams, voltage monitoring and remote services (connect/disconnect, contracted power and tariff setup, tampering alarms, etc.); it also offers a local connection for establishing a Home Area Network (HAN), allowing the consumer to access the information in the EB in real time (ZigBee and WiFi technologies have been used for the HAN);
- Distribution Transformer Controllers (DTC) installed in every secondary substation, acting as data concentrators and local measuring, monitoring and automation devices (power quality monitoring, medium voltage switching, local sensors, etc.); the DTC controls every EB connected to its low voltage network, independently of the technology used for communications;
- A communications network based on Power Line Carrier (PLC) and GPRS technologies between EBs and DTC (Radio Frequency Mesh has been also tested), and based on GPRS or any other TCP/IP supporting technology for connecting DTCs to the central systems;

- Central commercial system (head end + meter data management) for metering data and low voltage SCADA-like system for grid operation data, both communicating with DTCs, but using different protocols.

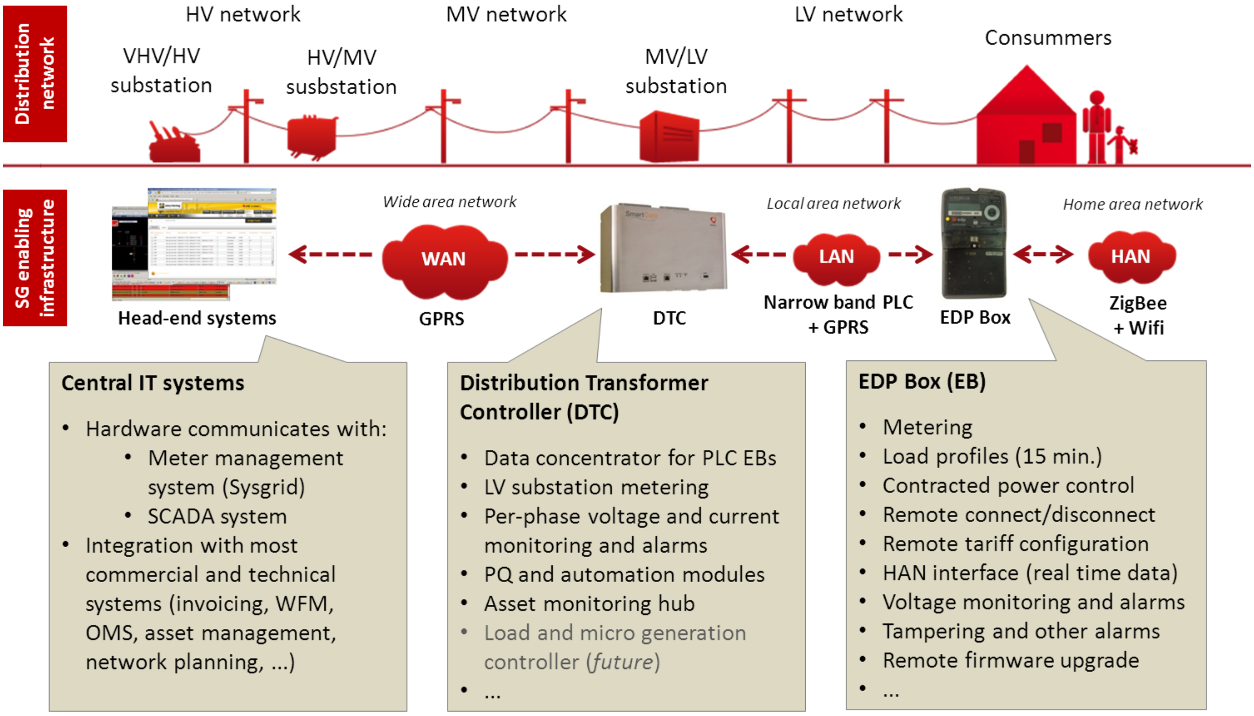

Figure 3: Inovgrid architecture

The mix of components and technical architecture used in Évora, depicted in figure 3, goes well beyond smart metering, serving other applications such as LV substation monitoring and automation.

The business case

Inovgrid embraces all the different aspects of the smart grid ecosystem, from the central information systems to the end users, from the smart meter to the electric vehicle charging infrastructure, and being an open platform by construction it fosters innovation from all the participants in the ecosystem and provides the favourable environment that allows the evolution and creation of new business models, services and products that will ultimately benefit the different stakeholders.

The business case for Inovgrid is based on a set of benefits of the project accruing to several stakeholders, including the DSO itself, electricity users, electricity retailers, producers, energy services companies, and the economic and ecological impact in society in general. The deployment in Évora provided ample evidence about many of these benefits.

The diagram in figure 4 illustrates the main estimated and/or measured benefits of the project. For each of those benefits, Inovgrid created a team responsible for analysing, promoting and measuring it, whenever possible. This effort paid well, because it allowed EDP Distribuição to reach and measure some relevant results supporting the business case, and definitely contributed to the credibility of the project.

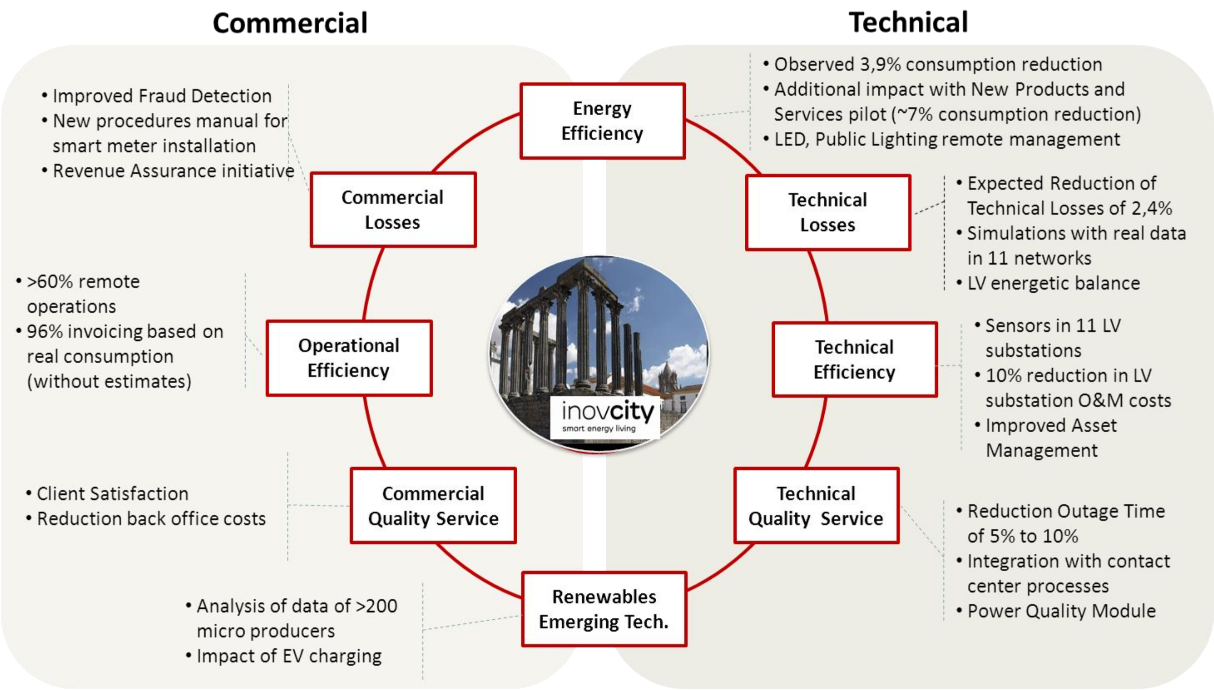

Figure 4: Areas of benefit of the project

The evidence obtained has supported EDP's assessment of the societal implications and cost-benefit analysis of a full smart grids rollout and the conclusion that smart grids have the potential to create substantial value for the society as a whole. Meanwhile, an independent study commissioned by the Portuguese regulator (ERSE) and produced by KEMA [3] reached very similar results and conclusions. The graph in figure 5 illustrates how the main benefits of a smart grid rollout are divided among different value drivers, in EDP's business case analysis.

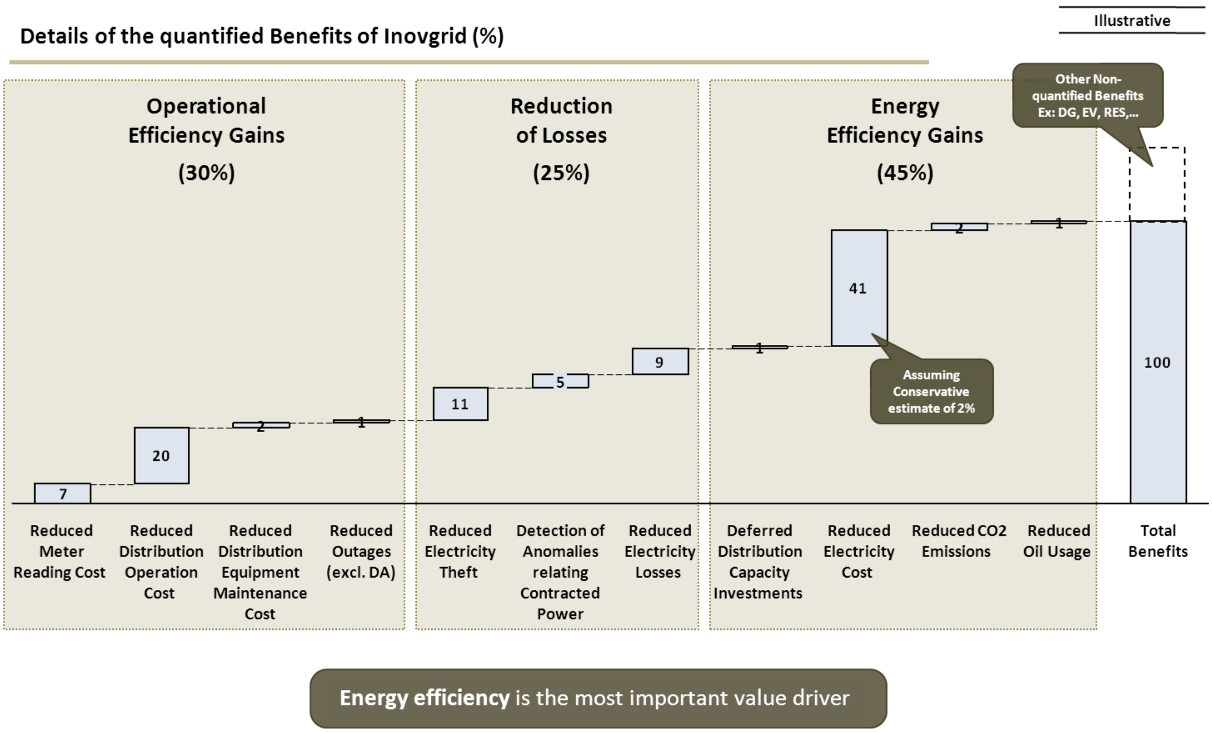

Figure 5: Main benefits

Energy efficiency results from the Inovcity

From the beginning of the pilot in Évora, EDP understood the crucial impact of energy efficiency on the value of the project. Considering the critical role that customer engagement plays as a prerequisite to change behaviours and increase energy efficiency, EDP implemented in Évora a mix of initiatives aimed at raising awareness about the project and creating a special Inovcity dynamic. Key stakeholders were identified and multiple initiatives were designed to target specific customer groups and other stakeholders, such as schools, energy professionals and local authorities. Several activities of communication and dissemination of the project were key to get the involvement of different stakeholders, as shown in figure 6: the Inovcity showroom, the Energy Bus, the information spread around the city of Évora, the organization of Conferences and events, the presence in the local press or even the public sessions held for customers' clarifications of the project. Additionally, surveys were used to continuously monitor customer behaviour and guide communication decisions.

Figure 6: Local initiatives promoted awareness about the project

Regarding residential low voltage clients, a very broad study, including data from more than 30 thousand customers was developed together with Qmetrics, an independent company specialized in market studies and integrating university Professors from Universidade Nova de Lisboa. The basis of the study consisted in monitoring the electricity consumption of customers in Évora and comparing it to a control group in a nearby municipality, with similar socioeconomic and climatic conditions. An evaluation of results was done after gathering an initial 12 month of data, and their persistence was evaluated by monitoring consumption for an additional year.

The group under evaluation had their meter replaced by an EDP Box, started receiving monthly invoices based on real consumption (instead of estimates), had the possibility to monitor their consumption online (web portal) and were exposed to the general project communication effort in Évora, which included generic energy efficiency advice.

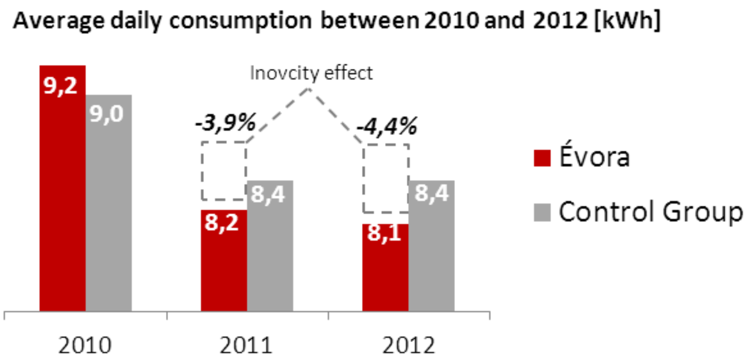

Figure 7: Average daily consumption between 2010 and 2012

The results in terms of energy efficiency, shown in figure 7, were highly encouraging: in the first year an average reduction of consumption of 3.9% vs. the control group was observed. Furthermore, this was a statistically significant result, with the result falling in the interval of 1.8% to 6% for a 95% confidence interval (2.1% error margin). This applies to the whole Inovcity, around 31.000 consumers, assuming basically indirect feedback.

The data gathered so far also shows that the effect is persistent (4.4% energy reduction in the second year), at least two years after the project was launched. This result of about 4% increase in energy efficiency provides a comfortable margin when compared with the conservative estimate of 2% used in EDP's business case. The previously mentioned study performed by KEMA [3] considered several analytical scenarios, using figures of 1% and 2% for energy efficiency using indirect feedback, and 3% for direct feedback using in-home displays.

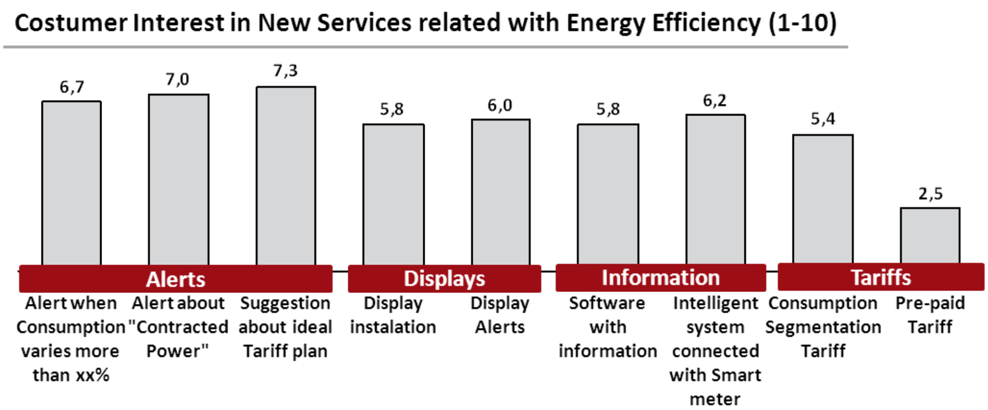

Figure 8: Costumer interest in new services for energy efficiency

Beyond the impact of the project in the general population of Évora, EDP used the pilot to test the impact of more sophisticated smart grids products and services, using smaller test groups. The first step consisted in conducting surveys and focus group sessions to understand customers' preferences, whose results are presented in figure 8. From several possible new services (such as alerts, in-home displays, applications for delivering useful information and tariffs), customers elected the alerts as the most interesting ones. Pre-payment was considered the least interesting service.

In order to touch different customer segments, several innovative services were tested in a set of customers ranging from large companies to individuals. Aspects like energy efficiency, CO^2 reduction, energy consumption reduction, smart consumption patterns were taken into account in providing these innovative services, which targeted not only economic aspects but also social and behavioural aspects.

EDP's desire to promote the active participation of customers was reflected in the technical specification of the EDP Boxes, which are prepared to accept a HAN module that allows the flow of information from the EDP Box to the customer premises, interacting in real time with devices such as in-home displays, energy controllers or the customer's WiFi router (figure 9), thus providing direct feedback.

In Évora, EDP provided in-home displays to a test group of customers and instructed them on how to use this data for their own benefit. Complementary, for another test group, simulated tariffs were introduced to allow customers to compare their real consumption pattern with what they would have achieved if they had chosen a different tariff and rewarding their energy efficiency. Frequent surveys were conducted near the target population to have a deep understanding of the evolving customers' perception, and focus groups were organized to extract additional feedback. For both, groups alerts were sent to customers based on individual consumption information (e.g. SMS, email). Results from these two groups are also encouraging, with observed increases in energy efficiency of around 7% (6.7% to 6.9%), but a higher error margin.

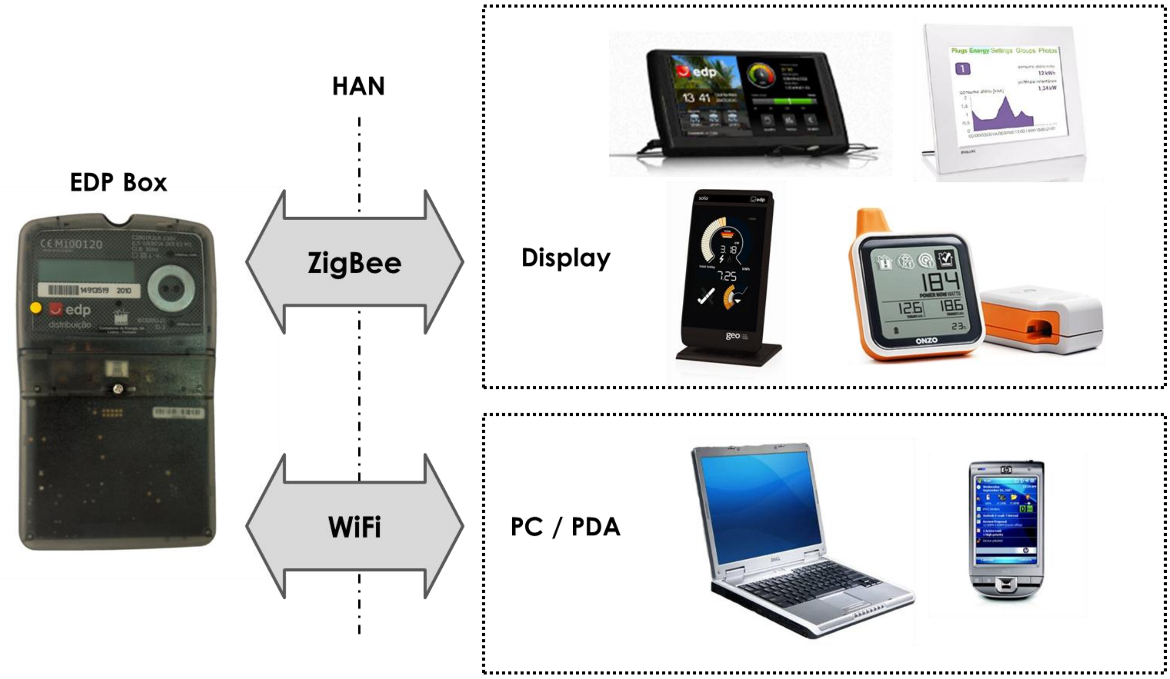

Figure 9: Home Area Network (HAN) interaction

Inovgrid technology is currently used as an open platform, based on public standards, by other independent companies developing new in-home tools and services supporting customers' involvement, which allow to deeply empowering consumers to make smart decisions about electricity consumption. Customer innovative products are under test, leveraging on Inovgrid platform but developed by independent companies.

So far results for heavy consumption customers' with sophisticated energy management systems, like Hospitals, Museums, Public Buildings and others show that significant energy savings are achievable and gains between 12% and 20% of consumption reduction were observed.

International cooperation

The Inovgrid project is being developed in close cooperation with several organizations including Research Institutes and Universities across Europe, Industrial Partners, Local and National Authorities, Energy Sector Associations and Regulators, the involved Communities and other relevant stakeholders. Delegations from more than 30 countries from all continents, ranging from Australia to China, or Brazil to Angola, have visited Inovcity Évora.

The company participates in several European projects with major R&D components included in FP7 or IEE programs which foster innovative beyond the state of the art research and validation across different European Member States. EDP Distribuição leading a consortium of 8 partners was chosen to implement a major European Research and Development project named Sustainable. Partners include several R&D Institutions like INESC Porto, Comillas University from Madrid, National Technical University of Athens, University of Manchester or the Technical University of Berlin. The focus is the shift of paradigm in the distribution network concept of operation which strongly leverages in recent smart grid projects and aims at an increasing capacity of renewable energy hosting, allowing decarbonizing the economy. Other relevant projects where EDP participates is the EcoGrid project, which is an European project whose objective is the development of a new type of market with electricity prices in near real-time information, and which was nominated in the UN Conference of Sustainable Development (Rio+20) in June 2012 as one of the 100 most sustainable projects in the world, and it was one of the 10 finalists in the category of "Best IT Solution".

From a universe of more than 200 Smart Grid projects under development in Europe, compiled in a Smart Grids Project Catalogue by the Joint Research Centre Institute for Energy and Transport (JRC) and Eurelectric in 2011, Inovgrid was selected as the single case study for testing and validation of the EPRI Business Case assessment methodology. Following this selection and building in the work done at European level, Inovgrid was assigned the "Core Project" label [4] from the European Electricity Grid Initiative (EEGI), being one of the 4 projects that achieved it so far and being the only national project of the group. This shows full commitment and alignment between the identified European project needs and Inovgrid project, not only targeting new technological developments but also a very strong focus on customer service innovation. Figure 10 illustrates this international involvement.

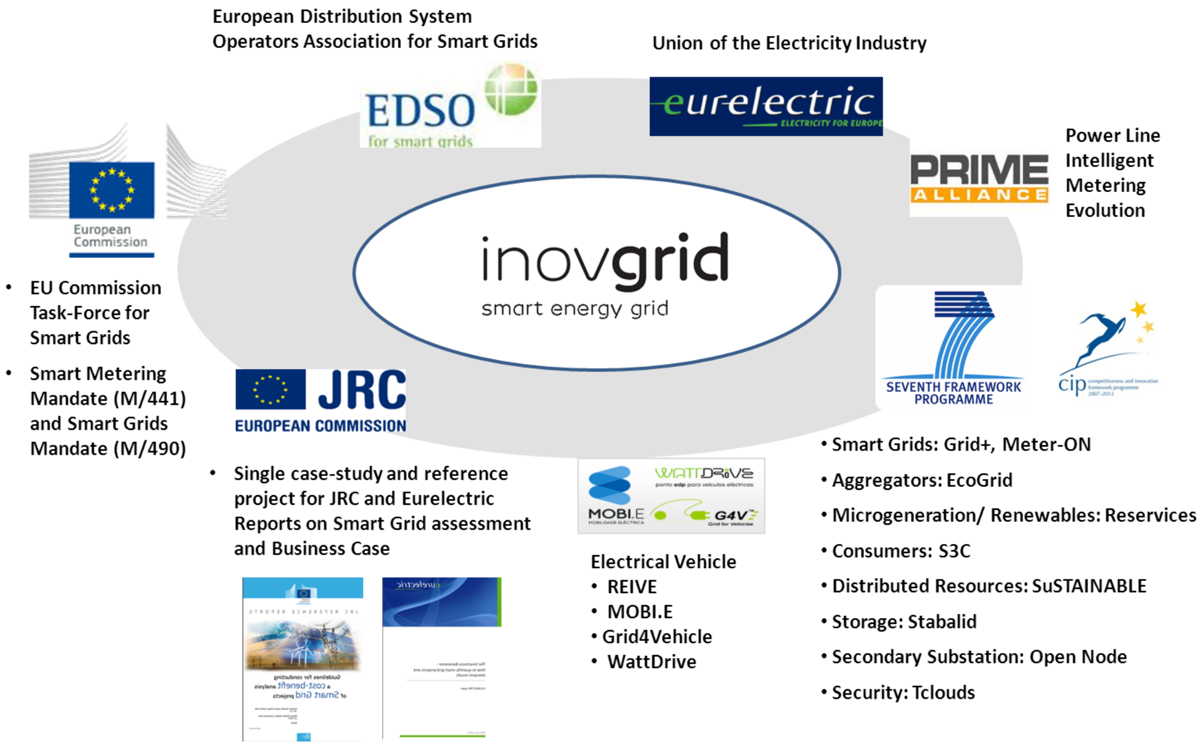

Figure 10: International cooperation in Inovgrid

Conclusions

Results from Évora provide ample support for EDP's business case for a nationwide rollout. Furthermore, EDP's results are aligned with those of the Portuguese regulator in concluding that the rollout of the Inovgrid solution would create value for society.

Consumer engagement is key to unlock the smart grid potential. Utilities face big issues today as they search to maximize consumer engagement – being able to manage the millions of data available, understanding the new and all different consumers, being able to build-in innovations in their operations and also focusing on maximizing value for all stakeholders.

Évora is a living lab for the Inovgrid project, with different valences from smart metering, public lighting, electric vehicles, energy efficiency and Client interaction, and the project has developed a strong involvement of local stakeholders and population which was key for its success

The results of the Energy Efficiency Study in Évora show that the implementation of a Smart Grids infrastructure led to an increase in energy efficiency of around 4%. Additionally, new products & services are being tested on selected segments of customers to understand the impact of different incentives in consumer behaviour.

EDP Distribuição is looking ahead in the smart grids and consumer engagement topic: first, it plans to install an additional 100k EDP Boxes in 6 locations with different network characteristics in Portugal; secondly, EDP Distribuição is aligned with the most important standardization projects in Europe and actively participates in several international forums and projects.

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SMARTplug: Using smart devices for a managed charge of electric vehicles

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Abstract

Electric vehicles are seen as an option to reduce greenhouse emissions from the transportation sector and their number on the road is growing in a daily basis. However, with their widespread adoption the increase in the demand for electricity to charge these vehicles could pose significant challenges to the electrical grid in terms of additional load due to unmanaged charge strategies. In order to mitigate this problem, the charging of the electrical vehicles must be managed. This paper presents the development of a hardware and software architecture to dynamically control the charge of electric vehicles to maintain the proper operation of the local distribution grid, by reducing the possibility of power outages due to overload, in a Smart Grid context. The hardware consists in two modules, a meter and controllable plugs both with communication capabilities, while the software consists in a load forecast and scheduler module. The load forecast is calculated based on the power consumption behavior and is used to assign the best time slot to charge the vehicle. The system aims to minimize the load peaks and flatten the load profile.

Based on the user preferences, system characteristics and consumption forecast, the system will assign the most suitable time slot to charge the electric vehicle. For the case of multiple electric vehicles, the system will schedule their charge based on a calculated priority level, in order to maintain a reliable operation of the local electrical grid.

1. Introduction

Electric Vehicles (EVs) are expected to have a large share in the future of the transportation system in order to reduce the share of Greenhouse Gas (GHG) emissions associated to personal transport and also due to the increasing costs of fossil fuels [1] [2]. This electrification of the transport system will cause an additional load on the electric grid, since the EVs will require a connection to the grid to charge the batteries. Currently, due to the EVs low penetration rate the additional load imposed to the grid by the vehicles charging is not an issue, however in the future, with a higher penetration rate, this could bring serious consequences to the grid reliability due to overload [3] [4]. The main problem is not in the extra energy required to charge the batteries, since the grid has enough capacity, but the peak load of the charging [5] [6].

Since the majority of EVs will be charged at home, it is expected that the vehicle will be plugged in when their owners get home, at the end of the afternoon. This behavior will lead to a considerable additional load that can overload the grid. In order to mitigate these problems, the charging cycle of EVs must be managed in some way [7]. This concept of coordinate charging is being explored due to the wake of smart grids, where the exchange of information using several communication technologies can improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity [5] [8]. Coordinate charging can also be beneficial for grids with a large share of renewable energy sources by absorbing the excess energy produced [9].

Alternatives to uncoordinated charging are currently being investigated by using devices with bi-directional communication capabilities to perform a coordinated charging [10] [11] [12]. This type of coordination is intended to minimize the negative impacts on the grid, due to a large number of vehicles charging at the same time by distributing this charge over a large period of time, flattening the load peak. Efficient operation in a smart grid environment usually is focused in reducing energy losses and increasing efficiency [13] [14], in this paper the focus is in maintain the grid stability by avoiding the overload due to the uncoordinated introduction of additional loads.

2. Motivation and Problem Definition

Intelligent control over the introduction of new loads into the grid has the potential to provide economic benefits since peak demands affect the grid investments and operational costs [15] [16]. Minimizing demand peaks by distributing the load over a longer period of time will contribute to reducing the transmission and distribution losses, since these losses grow with the square of the current, and stress in the grid equipment [17] [25]. In order to flatten the load profile, some utilities apply different price rates depending on the time of day to encourage customers to shift the use of certain appliances, such as washing machines, to off peak hours when electricity price is cheaper. This approach contributes to the reduction of peak demand, however this implies active consumer involvement which can be difficult to manage. Relying on consumers to manage their energy consumption to off peak hours can work during an initial period, where they are motivated by the novelty and savings that can be achieved, however after this initial period they will start to revert to old habits. Using an automated system that takes into account user preferences, to manage the loads is a better solution since the system will automatically adapt by continuously evaluating the grid status and could also allow the utility to disconnect/connect loads in certain situations [18] [19] [22].

Since EVs are a significant load (around 3.6 kW during the charging cycle of the EV, which can last up to 6-8 hours), the use of an automated load management system can contribute to an automated demand response program controlled by the grid. This demand response system refers to the ability to reduce loads at peak times to lighten the need for peaking generation sources. These power plants are usually gas turbines that burn natural gas, due to their fast response, and since they only supply power occasionally, the price per kilowatt hour is much higher when compared with the price for base load power plants. The shift of these loads to off peak hours can also contribute to a reduction of GHG emissions due to an increasing in the efficiency of gas and coal power plants [24].

Loads equipped with communication and control capabilities can be aggregated and dispatched to help to manage the grid. This load aggregation can provide the same regulation as ancillary services, nowadays provided by power plants. This regulation is very valuable since it provides real time matching between load and generation. Without this equilibrium the grid frequency will drift up or down affecting the quality of service [20] [21] [25]. Despite the benefits for the network in terms of increased reliability, this service provided by EVs is also beneficial since it will have a financial revenue associated [22].

Nowadays this regulation is achieved by forecasting the load based on past data and dispatch of generation accordingly, however this load following approach becomes more difficult as the share of renewable generation increases. The intermittent nature of renewable energy sources, such as wind and solar, makes very difficult to predict with certainty their contribution to the total generation and can require more conventional generation sources used as backup to provide ancillary services and regulation to the grid.

The introducing in the market of vehicles with the capability to be plugged into the grid associated with a daily commute distance under 50 km (which requires up to 10 kWh of energy) for the majority of the users will make the EV one of the major energy consuming devices in a household. An EV charging, using a Level 2 charging station will draw 3.6 kW of power during around 3 hours per day for a 50 km commute. Based on the commute profile of the users, is reasonable to expect that EVs will be plugged in at least during 8 hours per day (or more if the EV is also plugged in at work and not necessarily charging during this period) which is more than the required time to restore the energy spent, resulting in a flexibility that also can be harnessed to provide grid services while ensuring the requirements of the user.

EVs could be an excellent demand dispatch resource given their potential for rapid response (can be turned on or off in a matter of seconds), the significant amount of power that they can draw during large periods of time and expected market penetration. It is possible, that in the future, a significant part of the ancillary services to provide regulation to the grid will rely on EVs.

3. SMARTplug System Architecture

This paper presents the development of a hardware and software architecture for demand response, where the main goal is to manage in real time the additional load introduced by EVs when charging at home, avoiding triggering the installation protections due to overload (Figure 1). This management also intends to flatten the load profile by shifting the peaks to the valleys based on user preferences, EV battery State of Charge SoC and local installation power capabilities. The system requires the following parameters from the user:

- Contracted power: Defines the maximum amount of power that can be used from the grid without tripping the installation protections. If at a given moment the present or foretasted power reaches 80% of this value, the electric vehicle is disconnected or the time slot is considered invalid for charge, respectively.
- Vehicle charger power: Specifies the amount of power that the electric vehicle will draw during the charge cycle (for a Level 2 charger this value is around 3.6 kW).
- Battery SoC required: Specifies the maximum state of charge for the electric vehicle.
- Unplug time: This time defines the deadline to achieve the required battery state of charge.
- Energy tariffs: Specifies the different costs of the consumed energy to different time periods. If several time slots are suitable to charge the electric vehicle, the chosen one will be the one with the lower tariff.

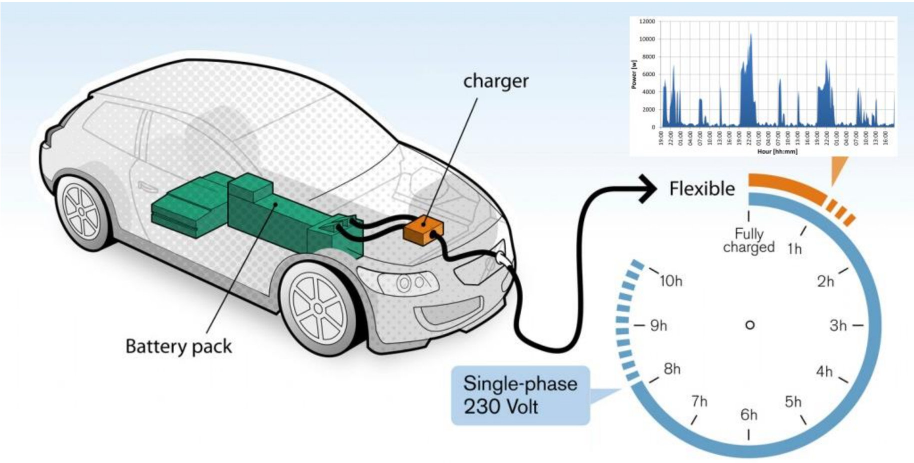

Figure 1: Scenario where is possible to implement the SMARTplug system. The system is aimed for a residential environment, with a single or multiple charge points.

Hardware Architecture

The system, described as SMARTplug, is composed by two main devices, an energy meter and a smart plug (Figure 2), both with communication, data storage and local processing capabilities. The energy meter is installed on the feed point of the infrastructure, to measure in real time the global energy consumption, while the smart plug will replace the standard plug used to charge the EV. The energy meter will also store the load diagram from at least the previous three weeks. Depending on the number of charging points for EVs, it is possible to have multiple intelligent plugs in the same infrastructure, but only one energy meter is required. For a single charging point it is possible to integrate these two devices into one to avoid complexity and reduce costs.

The stored data is used to forecast the load during the time when the electric vehicle is plugged in and to assign a time slot to charge the EVs. If the EV is plugged in eight hours and only requires two hours to achieve the desired SoC, the time slot chosen will be the one with the lower tariff, with the lower footprint and the lower impact on the load diagram in terms of peak power.

Both devices have a dedicated energy measurement unit that calculates all the relevant parameters (voltage, current, energy, power and power factor). The micro-controller communicates with the energy measurement unit through RS-485, and stores the power data each minute. The smart plug additionally has a solid state relay used to turn on and off the power. The communication between the two devices is currently done by RS-232, but another communication interfaces could be used.

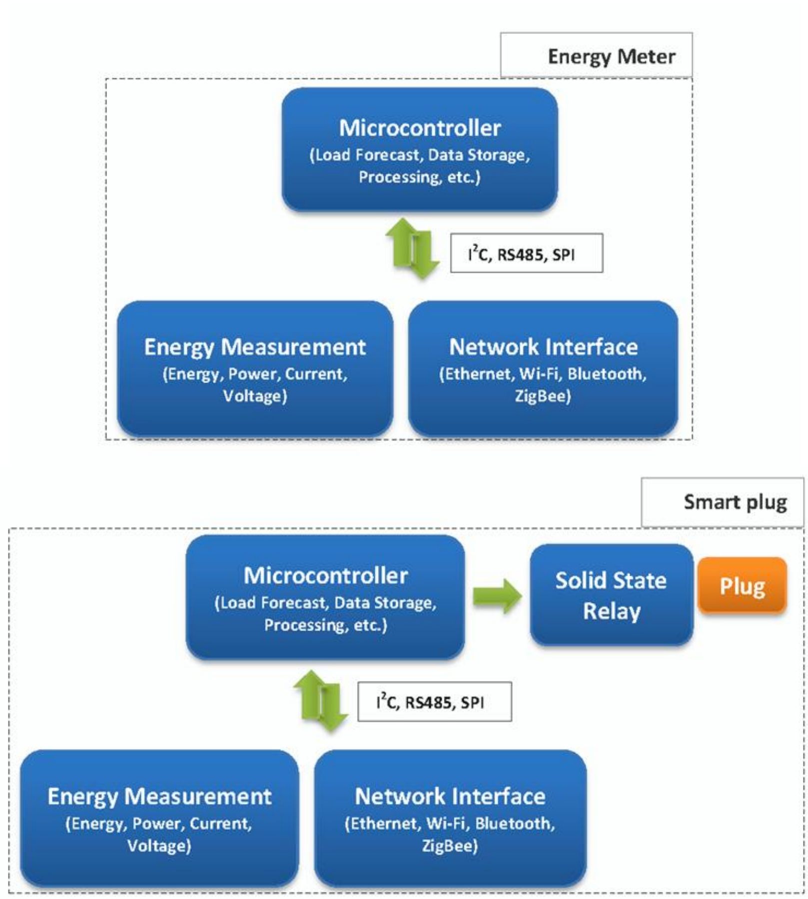

Figure 2: SMARTplug system architecture with the energy meter (top) and the smart plug (bottom).

Software Architecture

In terms of software architecture, the SMARTplug system has three main components: a load forecast module, a classifier module and a scheduler module. The Load Forecast module is responsible to forecast the load based on previous data. This module uses the power data stored by the energy meter, excluding the contribution from EVs charging stations, for the global power consumption. The forecast is performed by using the average previous data for the same time frame and taking into account if it is a weekday or weekend, since the load diagram varies significantly from weekday to weekend. The forecast is performed with a five minutes interval, despite the data being stored each minute.

The Classifier module (Figure 3) is responsible by the analyses of the time slots where the charge of the EV may occur and classify them as valid or invalid. This module will run when the EV is plugged in and based the load forecast, electricity price, contracted power and power draw by the vehicle will determine a set of valid time frames to charge. The load forecast for a given timeslot considers the past five identical timeslots (e.g. the load from the previous five days at 15:00 hours) and is calculated using Equation 1.

Equation 1 $$L_t = \sum_{n=1}^{5} \propto_n \cdot L_n$$

Where L_n is one of the past timeslots and $\propto_n$ the weight factor considered for that timeslot. A given time slot is only valid if the contracted power is higher than the load forecast plus the power draw by the vehicle. The availability of a time slot is calculated using Equation 2:

Equation 2 $$A_{vt} = P_{cont} - (F_{pt} + SM) - P_{ch}$$

Where P_{cont} is the contracted power, F_{pt} is power consumption forecast for time T, P_{ch} is the power of the EV charger (3.6 kW for Level 2) and SM is a safety margin (0.2 kW). From Figure 3 in the validation of availability, depending on the ratio between A_{vt} and P_{ch}. a grade is assigned. The values for the grade were chosen arbitrarily to penalize time slots with high energy tariffs and demand forecast.

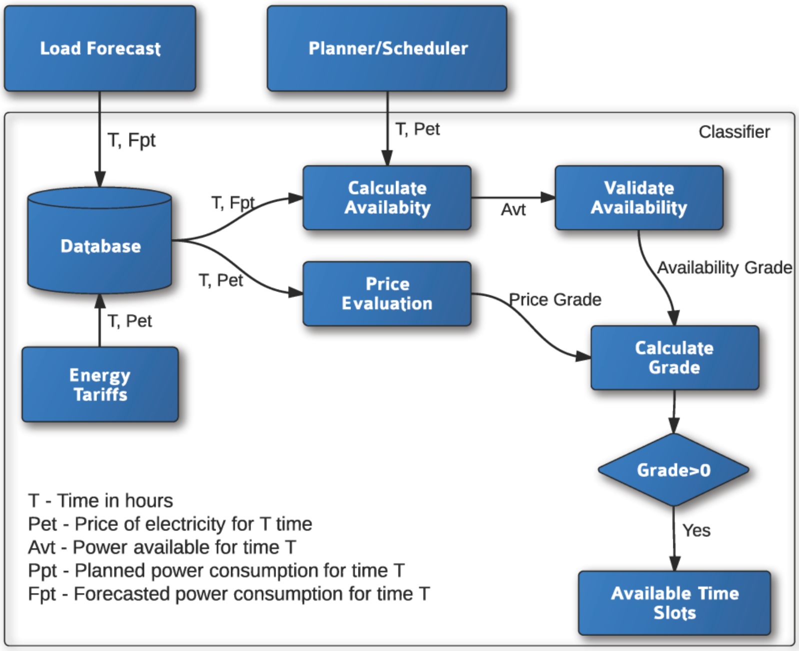

Figure 3: Diagram for the classifier implemented in the SMARTplug system. The classifier determines the valid time slots to charge the EV based on the load forecast, electricity price and planned power consumption.

The Scheduler module (Figure 4) is responsible by the generation of a charge plan. After the validation of the time slots, the planner will assign the best slot to charge the vehicle, based on load requirements (in this case the load is the EV).

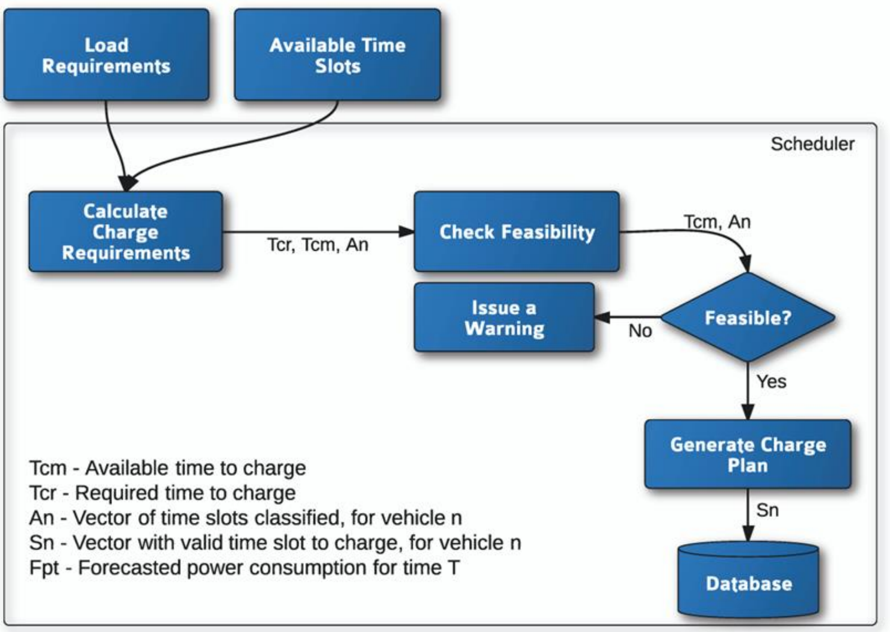

Figure 4: Diagram for the scheduler implemented in the SMARTplug system. The scheduler generates a charge plan based on the available time slots and load requirements.

The load requirements are the capacity of the battery, the SoC of the battery when the vehicle is plugged in, the required SoC and the time of unplug. Based on these parameters the charge requirements are calculated using Equation 3:

Equation 3

$$T_{cr} = \left(B_{cap} - B_{cap} \times \frac{SoC_{ini}}{100}\right) \Big/ P_{ch}$$

Where T_{cr} is the required time to charge in hours, SoC_{ini} is the initial SoC in % and B_{cap} in kWh is the useful battery capacity (on the Nissan Leaf from the 24 kWh only 20 kWh are useful). The feasibility is only validated if a set of available time slots required to charge the vehicle are less or equal than the ones available. If several sets of time slots are available to charge the vehicle, the chosen one will be the one with less impact in the load diagram.

Load Diagram Analyses

To understand the extent in which the management of the additional load introduced by EVs could be controlled by a system with minimal intervention by the user, it is important to have detailed information regarding the energy consumption during a large period of time. Figure 5 represents the load diagram for an average European household [23].

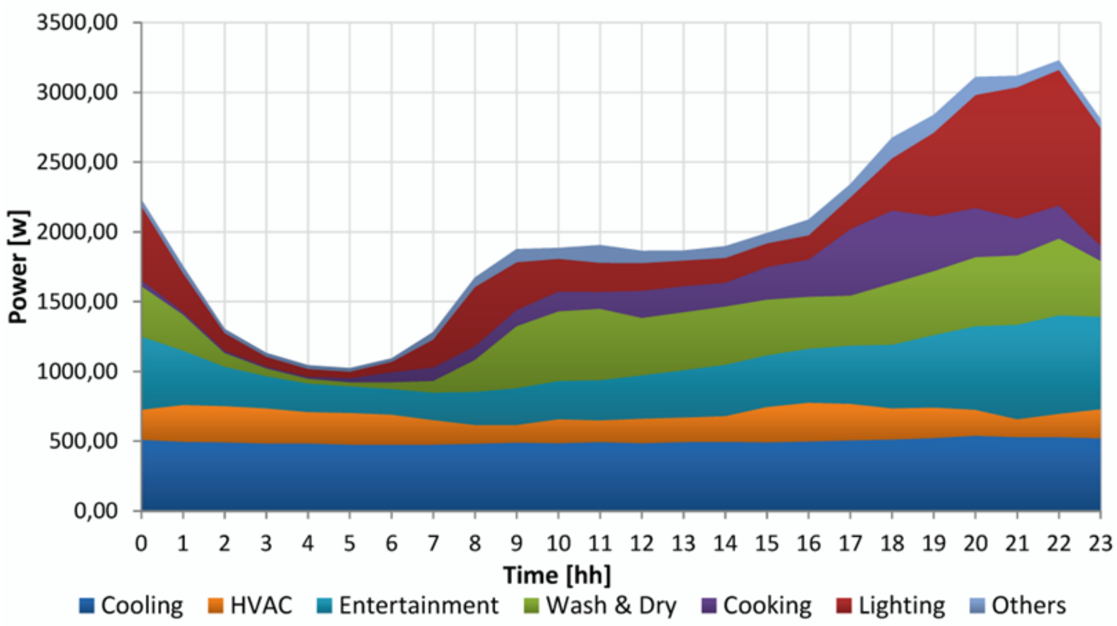

Figure 5: Load diagram, by type, for an average European residence during a day [23].

From Figure 5 it can be seen that the majority of the power consumption occurs between 17:00 and 00:00 and between 01:00 and 07:00 the consumption reaches its minimum. By analyzing the load diagram, is visible that the best time to charge an EV is between 01:00 and 07:00, however this implies that the user must plug in the vehicle or program it to charge during this period. Despite this being a valid solution, this implies active participation from the user, and as referenced before, cannot be guaranteed that the charging will occur at optimal times.

Figure 6 and Figure 7 show an extract of a load diagram for two residences that were monitored, A and B, for a weekend and three days of the week [23]. These load diagrams are only for the household loads, excluding EVs. By observing the load diagrams it is visible that the consumption is concentrated in specific points in time and is very similar from day to day. For a given residence the load diagram tends to be very stable for works days and weekends. Based on these facts and using consumption data gathered over time, the consumption for the next 12 hours can be predicted. Without access to this information it would be very difficult to the user to choose the ideal time to start charging the vehicle. The benefits of an automated system over the common approach, where the user is responsible for the process of start charging the vehicle, is that the system can choose the best time to charge the EV taking into account several variables.

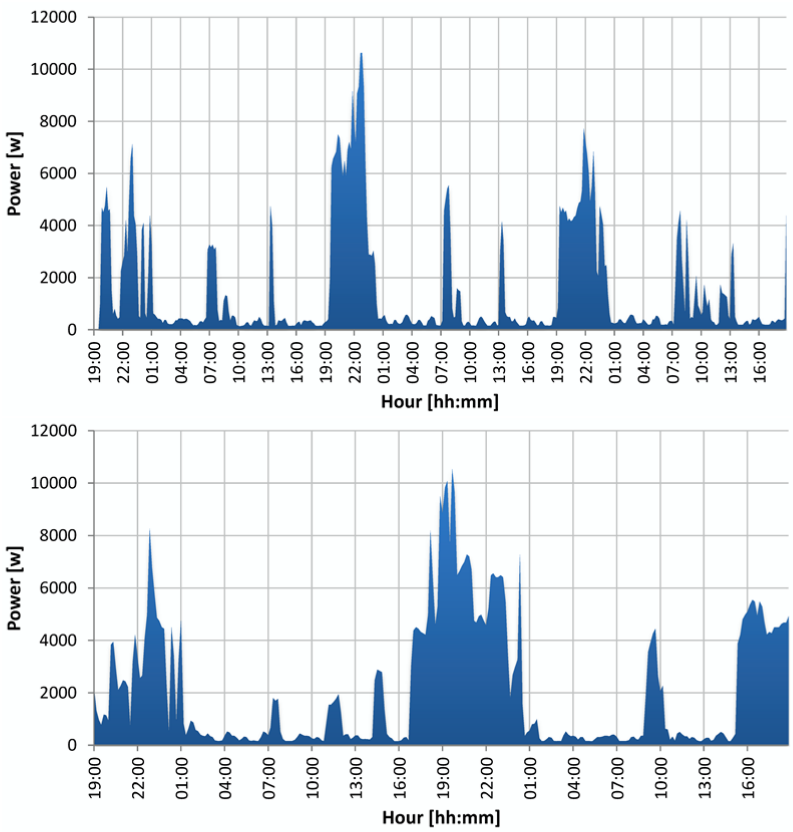

Figure 6: Load diagram for three weekdays (top) and for a weekend (bottom), for residence A.

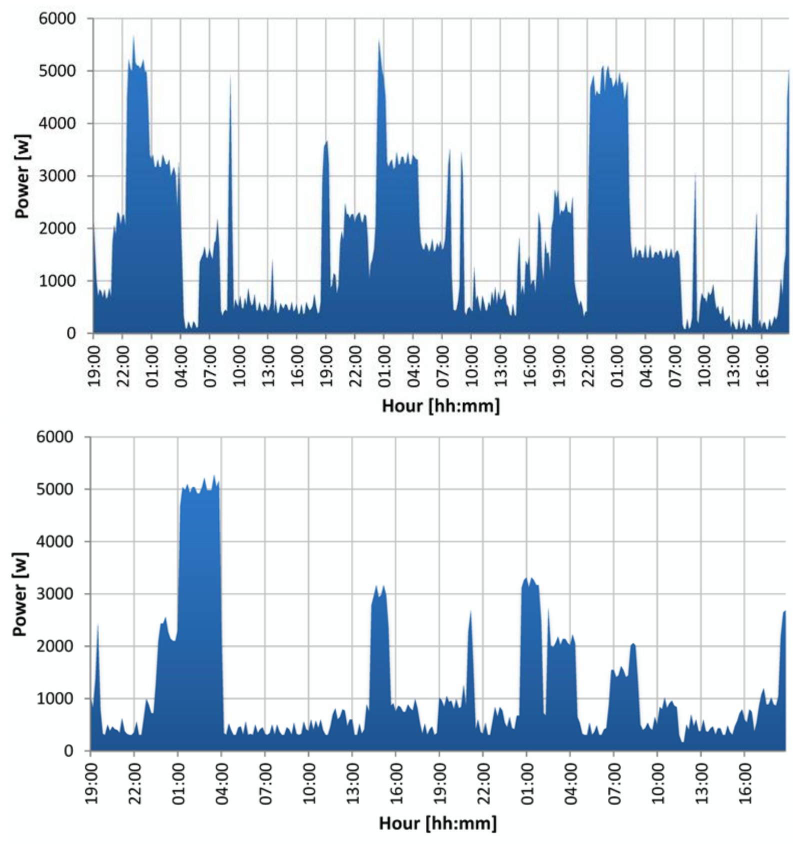

Figure 7: Load diagram for three weekdays (top) and for a weekend (bottom), for residence B.

To assess the impact that an EV can have in the energy and power consumption of a residence, the load profile during the charging cycle must be analyzed. Figure 8 presents the load profile of a Nissan Leaf for full charge and for a partial charge. The full charge absorbed 20.6 kWh of energy from the grid at an approximately constant rate of 3.6 kW during a period of five and a half hours. The profile of a partial charge is identical to the one of a full charge, except in the duration. This partial charge has absorbed 5.5 kWh during one and a half hour. For an EV with an energy consumption of 150 Wh/km, a charge of 20 kWh will provide a range of about 130 km, while a charge of 6 kWh will be suitable for 40 km.

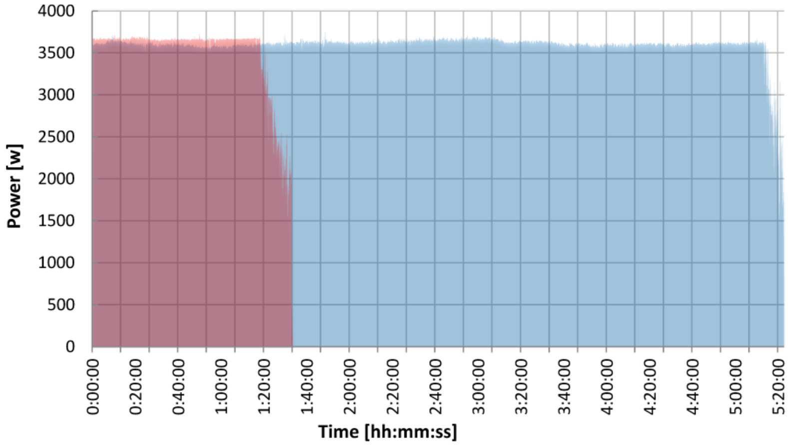

Figure 8: Charge profile for the Nissan Leaf over a full charge cycle (blue), with an energy consumption of 20 kWh over five and a half hours, and a partial charge cycle (red), with an energy consumption of 5.5 kWh over one hour and a half.

Figure 9 and Figure 10 present the impact of the additional load imposed by the EV in different scenarios, where the EV is plugged at 19:00 and must be fully charged at 08:00. The managed charge is based on the load forecast while the real load profile is presented for comparison. Figure 9 represents the impact of a partial unmanaged charge, where the vehicle starts charging when is plugged, and for a managed scenario, managed by the SMARTplug system.

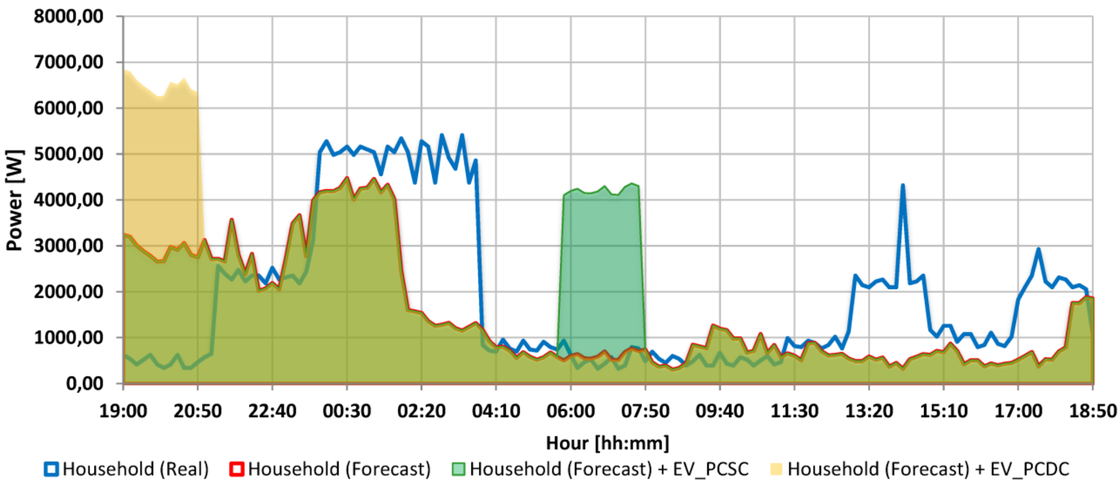

Figure 9: Load diagram (real and forecasted) for a household with an EV unmanaged (EV_PCDC) and managed (EV_PCSC) partial charge. The vehicle is plugged in at 19:00 hours and must be charged at 08:00. The charge takes two hours and consumes 7.2 kWh.

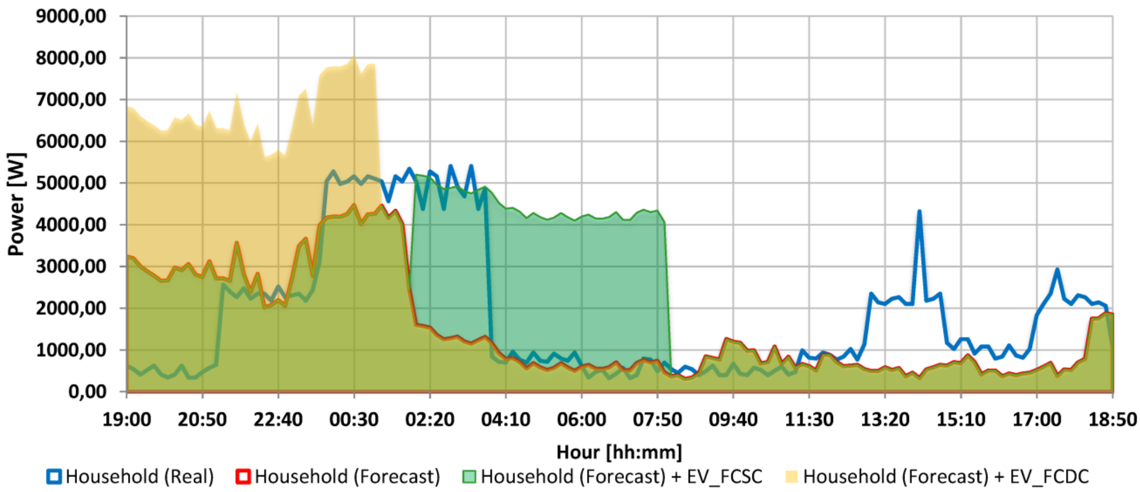

Figure 10: Load diagram (real and forecasted) for a household with an EV unmanaged (EV_PCDC) and managed (EV_PCSC) full charge. The vehicle is plugged in at 19:00 hours and must be charged at 08:00. The charge takes six hours and consumes around 21 kWh.

Observing Figure 9, it is noticeable that the managed charge has a better performance than the unmanaged charge since it will occur in the valley of the load diagram that take place during the night, when the energy is cheaper. The managed charge also reduces the peak power required to charge the vehicle, since it only tries to charge it when the forecasted power consumption for the household, in a given time period, is minimum. If the vehicle is plugged in only at 23:00 hours the peak power will be much higher and the household protections could be tripped due to overload. The benefit of a managed charge is more visible for full charge cycles where a large amount of power is drawn over a long period of time (Figure 10).

In this approach a simple forecast algorithm was used and by observing the load diagram from Figure 9 is noticeable that for given time periods the load forecast will not follow the real load accurately. This happens for periods where the load variation for a given time period is not very constant during the past days. Upgrading it to consider the different types of loads found in a household and include a model based on their use could improve the load forecast, however this approach would require a more extensive configuration of the system.

If multiple EVs are charge at the same time, the algorithm takes into account the charge plan of the remaining (their load is considered in the load forecast) vehicle. The system will give priority to the vehicles with tighter deadlines to achieve a pre-determined battery SoC. If a given vehicle cannot meet the user requirements, the user intervention is required to change the parameters.

4. Future Work

Despite the system architecture described previously being intended to be used in a residential infrastructure; it can be scaled to be implemented at the grid level. Since the same working concept could be applied (a smart meter installed on the feed point manages the smart plugs). In this case, the system architecture is divided into tiers and areas based on the power level and feed transformers, where each tier is associated with a power level and areas are associated to a given feed transformer. This approach decentralizes the decision making, where only the transformers directly affected by the power overload in a given area take action (by broadcasting a command to turn off loads). The control of the system, by a centralized entity, is also possible by introducing virtual loads into a given area to bind off loads. This capability is key for the implementation in a smart grid environment. The scalability of this system to manage other type of loads can be easily implemented, by installing additional smart plugs and setup a load profile, since each load has its own requirements. In terms of software, adjusting the time granularity, for the load forecast and planner/scheduler algorithm, based on the load diagram will contribute to reduce redundant calculations and speed up the algorithm.

Depending on the loads types, it is also possible to implement a strategy that will adjust the amount of power that each load requires in order to maintain the stability and avoid disconnecting loads. The use of a load balancing algorithm is also possible by charging the vehicle between power peaks.

5. Conclusion

In the future EVs will have an active contribution in the electrical grid management, due to a significant penetration ratio, by being able to absorb and inject power in a smart grid environment (Nissan already has a device that allows the EV to provide electricity to a household). However, nowadays even with a low penetration ratio of EVs and with the smart grid in an embryonic stage it is already possible to develop solutions that can implement some concepts from the smart grid. The capacity to inject power into the grid will lead to additional cycling of the EV battery, and contributes to accelerate the battery aging, however this impact will depend on the frequency that the grid will require this service. Due to cheaper electronics, standardization and mass use of communication infrastructures it is possible to develop a system than can be integrated in a smart grid, by implementing state of the art concepts without or with minimal intervention from the consumer, simply by updating the software in the device. By using a system similar to the described, the charging of an EV is straightforward and situations that can pose a risk to the household electrical system can be mitigated.

Despite the system architecture presented be originally targeted to provide a managed control of the charging cycle of EVs, it can easily be adapted to manage other loads in the household, however, this additional capability must take into account the load characteristics. With the evolution of the smart grid, both in terms of communication and management algorithms, this system can also be upgraded to integrate the new control strategies by simply updating the software and installing a new network interface card. Currently, demand side management requires the active consumer involvement, which is not very effective. By relying on a system that only requires the consumer input to specify its preferences, it can be shown that the additional load due to the charge of EVs can be easily integrated in the daily load diagram of a household without contributing to increase the peak demand. The system is also able to detected abnormal situations and notify the consumer (when it is not possible to meet the charge requirements) or act accordingly (when the EV is charging and overload situation is imminent the charge is stopped).

6. Acknowledgment

This work has been framed under the Energy for Sustainability Initiative of the University of Coimbra and supported by the FEDER/COMPETE FCT Grant MIT/MCA/0066/2009 (Economic and Environmental Sustainability of Electric Vehicle Systems) and FEDER/PORC FCT Grant CENTRO-07-0224-FEDER-002004 (EMSURE – Energy and Mobility for Sustainable Regions).

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Widening the Scope of the EU Energy Label

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Abstract

The European Energy Labelling Directive has been in place for 20 years, and is now closely linked to the Ecodesign Directive which sets minimum energy efficiency performance standards. The Commission is considering widening the scope of the EU Energy label by introducing environmental indicators. There is the need to consider the type and number of indicators; how to present these additional indicators; but more crucially the requirement to establish and calculate such indicators. We present appropriate methodologies and discuss the best approach to expand the label. We then consider what this new label may mean to consumers, their understanding of a more complex label and the influence it may have on their purchasing behaviour, given that they will not directly gain financially from that purchasing decision. The conclusions from the project were that although there is an array of methodologies to underpin different type of indicators, only a few are multi category indicators, such as the BP X30 323 or the Product Environmental Footprint methodologies. There is still considerable work required to develop robust and appropriate methodologies to underpin environmental indicators before they can be added to the European energy label. A debate is also required as to which indicators are most influential and how to educate consumers on their meaning. The consumer survey demonstrated a clear interest for more environmental information on products purchased and that consumers are willing to pay more for products with better environmental performance.

Introduction

This paper presents the findings of a European Commission funded project [1] delivered by a consortium led by Ispos MORI with Ricardo AEA and London Economics. The study considered how the scope of the current EU energy label could be widened, and how feasible it would be to upgrade it to include environmental performance ratings of products (carbon and water footprint, resource efficiency, eco-toxicity). The study tested consumers' attitude toward an upgraded energy label, through behavioural experiments, and whether they would pay more for a product which was better for the environment but that would not necessarily result in direct financial gains for them. In this paper, we first present a short overview of the Labelling Directive and its context, followed by an outline of how the current energy label could be upgraded and its implication. We then present a review and discussion of existing methodologies that could be used to underpin such changes to the energy label. Finally we report the high level findings of consumer behavioural experiment.

The EU energy label

The European Union (EU) has established competitiveness and sustainable development as two priority policies. Within this, sustainable industrial policy is a key area that aims to foster environmental and energy efficient products within the internal market. Energy related products are important because they are responsible for a significant proportion of the energy and other resources consumed by the EU. There is also considerable potential for reducing their associated environmental impacts by adopting ecodesign measures at the product design stage. It has been estimated that up to 80% of a product's life cycle impacts are determined at the design stage, whether these are emissions to air and water, water use or waste generation. The original Energy Labelling Directive (92/75/EEC) [2] implemented in 1992 was limited to the mandatory labelling of household appliances and the original Ecodesign Directive 2005/32/EC [3] focused on energy using products (EuP). The Ecodesign and Labelling Directives were recast in 2009 (2009/125/EC) [4] and 2010 (2010/30/EU) [5] respectively, extending the scope of the two Directives to include Energy-related Products (ErP) as

Figure 1: Original washing machine Label 1995

well as EuPs, ensuring the scope of the two Directives was consistent. This allowed labelling and implementing measures to be used in tandem for applicable product groups, e.g. televisions.

So what is driving the EC to widen the scope of the energy label? There are a number of key policies pushing this agenda, the Sustainable Consumption and Production Action Plan [6] includes a proposal to examine the addition of relevant environmental information such as emissions and resource-use over the course of a product's life cycle; however, it emphasised that energy labelling must remain simple, concise and efficient. It also includes the potential to introduce the carbon footprint of products into the existing EU environmental labelling instruments such as the Eco-label and energy labelling. In addition The Single Market Act [7] includes a specific objective on environmental footprinting: Proposal No 10, states that the Commission will consider an initiative on the Ecological Footprint of Products, including carbon emissions. The Resource Efficiency Roadmap [8] further strengthens and defines the future role of an environmental footprint methodology by explaining that the Commission will establish a common methodological approach to enable Member States and the private sector to assess, display and benchmark the environmental performance of products, services and companies based on a comprehensive assessment of environmental impacts over the life-cycle.

Energy Label Regulations are adopted by the European Commission on a product by product basis and show the ranking of products according to their energy efficiency/consumption, using categories in the form of letters from A+++ - G and a colour scale as presented in Figure 1. The Labelling Directive requires that manufacturers and retailers of products covered by the Directive display a comparative label on each model, at the point of sale. The primary goal of the energy label is to influence consumers to buy more energy-efficient products by providing information to help identify the better performing models. In the cases of refrigerators, dishwashers and washing machines, the energy label has been in place for 20 years, and has resulted in radically improved energy efficiencies, to the point that today, 90% of these appliances placed on the EU market reach class A and above. Such market transformation has been achieved by having a compulsory label that provides consumers with meaningful, credible, comparable and easy to understand information which brings directly measurable financial gains to consumers. Shift in the market and improvement in technologies prompted a review of the Labelling Directive (2010/30/EU) [5] and the introduction of the new categories A+ to A+++ and additional product specific information. The label today provides more than just the energy class of a product, it presents clear and comparable information for consumers on the energy efficiency; the energy consumption of the product (based on a specific EU-defined standard); additional product specific information including, for example for washing machines – load capacity, in-use water consumption, spinning performance and noise levels, using pictograms for ease of understanding, as presented in Figure 2. The current Labelling Directive (2010/30/EU) set a review of its effectiveness no later than 31 December 2014. The Commission has procured a number of projects to inform the review of the Directives, covering its successes, but also to understand how the Directive's scope might be further extended. Ricardo-AEA[1], as part of a

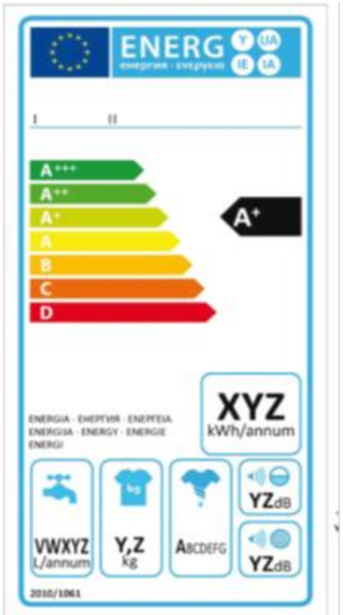

Figure 2: Washing machine Label 2010 [37]

1 Ricardo AEA was AEA at the time of the project

Consortium led by MORI IPSO, was appointed by DG Energy to complete this study.

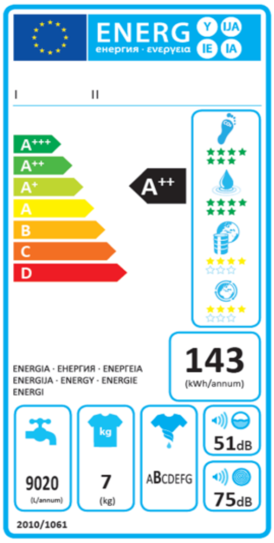

Figure 4a: Proposed Energy & Carbon Footprint Label

Figure 4b: Proposed Energy & Environmental Label

Option to extend the scope of the Energy Label

Any change to the scope of the energy label has to be carefully considered as this is a mandatory measure and is the principal mechanism to influence consumer buying behaviours. The potential additional information on the label must be as robust as the existing energy efficiency information; that it can be harmonised for a wide range of products, and is practical for manufacturers to implement. Finally it is vital to consider how the label might look, how consumers will respond to it, and whether they will understand the information displayed. The project looked at two distinctive proposals for widening the scope of the current label. The first option was an Energy and Carbon Footprint Label which added a carbon footprint indicator to the current label, see Figure 4a. The second option was an Energy and Environmental Label with four additional environmental indicators (carbon footprint, water footprint, resource depletion and water eco-toxicity), Figure 4b. The key aspect is that the additional environmental indicators would be taking a life cycle approach to the whole product rather than just the “in use” impact, which is what the current label provides. This raises key questions of how the scope be expanded to include life cycle based impacts and compared to “in use” only information. How can consumers make decisions that might require a trade-off between, for example, an A energy rating, but a B carbon footprint?

The symbols included on the proposed new label designs were as follows:

Figure 5: New indicators

Carbon footprint: The contribution to climate change made by the product throughout its life. This is based on the total greenhouse gases released covering raw material extraction, manufacture, use period by consumers, and disposal.

Water footprint: The amount of water used throughout the product’s life. For example the water used during production of the steel used to manufacture a washing machine, as well as water consumed during the use phase.

Water eco-toxicity: The poisonous effects of the product throughout its life on species living in rivers and seas and on the quality of fresh water. For example toxic substances released when the product is disposed of that affect the health of plants and animals in rivers.

Resource depletion: The rate at which this product leads to the depletion of natural resources faster than they are naturally replaced. For example the use of rare metals in the manufacture of a smart phone.

Literature review

The available literature on environmental product labelling was reviewed, including previous studies funded by the European Commission in this area. A key study by Ernst & Young and Quantis on Product Carbon Footprinting [9] identified 62 methodologies and initiatives for calculating carbon impact (some of the methodologies were multi criteria, so covered more than carbon footprinting), 11 of which were examined in more detail because of their particular relevance to informing EU policy. The "Analysis of Existing Environmental Footprint Methodologies for Products and Organizations" [10] followed, identifying and reviewing key methodologies and standards aimed at calculating environmental footprint of products and organisations rather than just carbon footprint. It retained just 7 of the 62 methodologies previously identified. Finally the "Product Environmental Footprinting (PEF)" [11] methodology developed for DG Environment, a guide on how to calculate Environmental Footprints (EF) and development of product category specific methodological requirements for use in Product Environmental Footprint Category Rules (PFCRs) was reviewed. This report presented the requirements to calculate a product's EF and outlines the underlying methodologies that should be used to carry out the assessment, based on a multi criteria methodology. Obvious synergies between the methodologies that could be used to calculate each of the proposed indicators within this project exist so that manufacturers will not be faced with unduly different methodologies for similar environmental labelling exercises. In addition, the PEF methodology has been developed through consultation and is based on pre-existing peer reviewed work in terms of the assessment method to be used for specific impacts. A review of these studies identified the use of common methodologies. Building on the above, this review searched for other methods (or updated versions of previously reviewed methodologies) not involved in the Commission's previous studies to ensure it adequately covered all four indicator agreed.

Review of available methodologies

This review assessed the most recently published studies to establish the scope of the methodologies, their reliability, and their applicability. The study reviewed 15 methodologies in detail ranging from ISO standards, through to company specific tools. Just two methodologies were identified as robust across all four indicators, the EU Product Environmental Footprint [12] and BPX30-32 methodology [13]. In the wider context of product environmental footprinting the European Commission's Product Environmental Footprint Guide [12] introduced the need for Product Environmental Footprint Category Rules (PFCRs). PFCRs are important as their aim is to provide detailed technical guidance on how to complete a PEF study for a specific product. The PFCRs concentrate on providing additional specification at a product level, thus increasing the reproducibility, consistency and relevance of product environmental studies. AFNOR[2], as part of the work within the BP X 3-323 [13] methodology is also in the progress of implementing "sectorial standards", to provide specific assessments for the product categories covered. These standards complement the overall methodology and ensure comparability between products of the same category (food, textiles, furniture, etc.). Table 1**Error! Reference source not found.** presents the reviewed methodologies and shows which indicators they apply to.

Table 1: Listing of the methodologies reviewed and which indicators they can underpin.

Methodologies	**Carbon footprint**	**Water Footprint**	**Resource Efficiency**	**Water Toxicity**
ISO 14044: Environmental management - Life cycle assessment 2006 [14] **-** Developed by the International Standard Organisation	✓	✓[3]	✓	✓
ISO 14067: Product Carbon Footprint 2012 [15] **-** Developed by the International Standard Organisation	✓			

2 French National Office for Standardisation

3 Indicators that are covered by the methodology, but not included in the list of relevant methodology for that indicator as over methodologies were deemed more appropriate,

Product Environmental Footprint, (draft 2012) [12] - Developed by the EC' JRC IEC.	✓	✓	✓	✓
ILCD: International Reference Life Cycle Data System [16] - Developed by the EC' JRC	✓	(✓)	✓	(✓)
Ecological Footprint Standard 2009 [17] - Developed by the Global Footprint Network.	✓	(✓)	(✓)	(✓)
Product and Supply Chain Standards Greenhouse Gas Protocol [18] - Developed by World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI).	✓			
Environmental Footprint BPX 30-323 [13] **-** Developed by ADEME[4] as part of a French law "Le Grenelle 1" [19].	✓	✓	✓	✓
PAS 2050 for Product Carbon footprint [20] - Developed by the Carbon Trust in the UK, and now published by BSI				
Sustainability Consortium [21] **-** Developed by a group of consumer goods companies, including Wal-Mart	(✓)	✓	✓	
Water Footprint Index ISO 14046 [22] **-** Developed by the International Standard Organisation		✓		
Water Impact Index [23] - Developed by Veolia Environment Research & Innovation in the USA		✓		
O2 Eco-Rating [24] - Developed by UK mobile phone operator O2.	(✓)		✓	
Vodafone Eco rating [25] - Developed by UK mobile operator Vodafone.	(✓)	(✓)	✓	(✓)
Usetox model [26] - Developed by UNEP-SETAC Life Cycle Initiative.				✓
Swiss Ecoscarcity model [27] - Developed for Switzerland by the Swiss Federal Office for the Environment				✓

Carbon footprint methodologies - Carbon footprinting is the most established and widely used environmental indicator, yet the first comprehensive label was only launched in 2008. Since then the field has developed significantly and a number of reliable methodologies and initiatives have become established. Today there are many different methodologies for the 'carbon footprinting' of products internationally, some focusing on life cycle carbon emissions, others focusing on the benefits derived by the company undertaking carbon analysis of their products. These methodologies and initiatives are broad in scope and fast evolving which has led firms, public bodies and other structures to develop their own methodologies to support their specific needs. This in turn has created a huge range of variation in, for example, the system boundaries applied, allocation management, and end of life treatment. Our review of carbon footprinting methodologies concluded that while it is important to take into consideration all the environmental impacts of a product in a balanced way; there is general consensus that a carbon footprint can be a good indicator of the overall environmental impact for specific product categories, especially those considered as highly energy intensive and simple in terms of emission sources (no land use change, no biogenic emission, etc.). Such findings are relevant to the potential addition of environmental indicators to the energy label. Yet this conclusion has to be balanced with the fact that greenhouse gas emissions are not always the most significant environmental impact, for example in mobile phones, and therefore other environmental impacts have to be taken into account to provide balanced life cycle information. Thus ideally the most appropriate methodology to calculate the carbon footprint as part of the energy label has to be one that offers the possibility of widening the environmental scope of the methodology to include environmental impacts other than greenhouse gases, as well as to ensure that the whole life cycle is considered in the analysis. This conclusion appears to support the proposal for an Energy and Carbon Footprint Label, in that overall a lower carbon footprint would also signal an overall lower environmental footprint. Within our review the two most promising methodologies were the **Product Environmental Footprint** developed by the Commission and **BPX 30-323,** due to the fact that they have both been developed with a strong stakeholders' input, resulting in a strong multi criteria approach which means that a carbon label could be a first step with the possibility in the future to further widen the scope of an Energy and Carbon label into an Energy and Environment label.

4 ADEME = French Environment and Energy Management Agency

Water footprint methodologies - Within the context of this study, a water footprint was defined as the amount of water used **throughout the product's life** from **resource extraction**, **manufacture**, **use** and **disposal**. The real-water content of products is generally negligible if compared to the whole cycle content. For example, a litre of milk contains nearly a litre of water, but the supply chain to produce one litre of milk has consumed 1,000 litres of water including water to irrigate the grass, concentrates to feed the cow, drinking water, washing water, cleaning water, cooling water and processing water [28]. This highlights the key reason why water footprints are gaining momentum as a way to educate and inform consumers. The process of considering a water footprint and prioritising improvements is more complex than carbon footprinting as the water returned to the environment may be returned with reduced water quality, or the water may be extracted when/where supply is scarce which makes it difficult to categorise the severity of the impacts. This makes comparisons more challenging due to the complexities that arise from global supply chains and water scarcity. There is also a close link between water and energy, which will be a key theme of future water strategies, particularly where water efficiency also results in energy savings [29]. While corporate water accounting methods and tools have been under development for the past decade, there is still a near universal agreement that current methods—though a good start—are inadequate and need to be refined [30]. For example there are no common definitions, - The Water Footprint Network [31] defines a water footprint as the volume of freshwater used to produce the product, measured over the full supply chain. It is a multi-dimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution; all components of a total water footprint have to be specified geographically and temporally. The European Water Partnership defines a comprehensive water footprint as one that should be split into three constituent elements, which are blue water (surface and ground water), grey water (polluted water from industry) and green water (volume of precipitation evaporated during the production process, most relevant to agricultural activities) [32]. The key achievement in this area is the development of the ISO 14046: Water Footprint Standard (still in draft format) which is based on an LCA approach as per ISO 14067: Carbon Footprint Standard. But, as mentioned earlier, the ISO standard alone will not guarantee that a methodology is fit for a mandatory label, and in order to be applicable within the context of mandatory labelling, changes to it would have to be made by policymakers.

Resource depletion - Within the context of our study resource depletion was defined as the impact of removal and use of, natural resources from the environment. This results in a decrease in resource availability of the total resource stock as non-renewable (usually abiotic i.e. non-living) resources are finite. Minimising the quantity of resources required to manufacture similar products, or increase the use of recycled materials will result in reduced resource depletion. Only a few methodologies cover this specific indicator, of the four methodologies reviewed in detail, half were developed by private corporations such as large manufacturers to support their brand sustainability claims. The methodologies embrace a life cycle approach as the results are often used to improve eco design at the conception stage or improve end of life management. The key methodologies that were highlighted were the French Environmental Footprint - BP X30 323, because it is developing a national database and implementing sectorial standards, and the draft Environmental Footprint of Product by the European Commission, which has been developed through stakeholder consultation process. The two methodologies developed by private corporation (the O_2 Eco-rating and Vodafone Eco rating) are both currently mobile phone specific and provide little transparency as the data is confidential.

Water eco-toxicity - Within the context of this study, water eco-toxicity was mainly concerned with chemical and heavy metals releases, reduction in biodiversity of the aquatic ecosystem, and fresh water quality. Our work sought to identify methods that quantitatively assess chemical risks to the aquatic environment i.e. methods that compile and generate data on the level of pollution that is released to the aquatic ecosystem and the impact on fresh water. It is worth noting that the chemical content of a product is strictly governed by regulation and covered under REACH [33] in the EC, which is not within the remit of this project. The tools reviewed here provide a framework to identify and quantify chemicals within a product or process that are released to water and what impact it has on the aquatic environment. As for resource depletion methodologies there is little work completed for methodologies on water eco-toxicity. There is little information available on initiatives aimed at labelling products or processes regarding water eco-toxicity impacts. On the other hand, this indicator benefits from LCA methodologies in terms of characterisation methods so as to be able to express the level of pollution as a possible indicator. A French product labelling experiment[5] that ran during 2011/12 included a number of products bearing an indicator or an overall eco score including water eco-toxicity. The products most likely to bear such indicators were water related products such as detergent, shampoos, washing machines or dishwashers. The methodology used to calculate the indicator had to be the BPX 30-323 as part of the experiment's requirements.

Conclusions from the review of existing methodologies

Of the four indicators considered, carbon footprinting is the most mature, with the most established methodology and it will soon be underpinned by an ISO standard. A number of products across the world already bear carbon footprint indicators. Water footprinting will also benefit from an ISO standard in the near future. These are important developments and are essential to underpinning product performance labelling in terms of the rigour and confidence they instil, although as noted previously an ISO standard is not a pre requisite for a robust methodology. The resource depletion and water eco-toxicity indicators are likely to be widely used by industry within the tools utilised when completing a life cycle assessment of their products. However the outputs are kept confidential and rarely publically released. Table 2 presents a high level review of the status of the methodologies available for each indicator. It should be noted that the judgement presented here considers how well methodologies are developed in the field of that indicator, rather than scoring each individual methodology.

Table 2: Level of methods' suitability for each indicator

Criteria assessment	**Carbon Footprint**	**Water Footprint**	**Resource depletion**	**Water Eco-Toxicity**
Life cycle approach - Do the methodologies consider the entire life cycle?	Green	Green	Green	Green
Reliability - Do the methodologies consider the entire life cycle?	Green	Orange	Green	Green
Robustness - Have the methods been reviewed and critiqued?	Green	Green	Green	Green
Maturity - How long have the methodologies been in used? This aspect considers the length of time that has been available for testing and further development reflecting market use.)	Green	Green	Green	Green
Degree of uptake - Is the methodology widely used by different market sectors and communicated?	Green	Orange	Orange	Orange
Credibility - Considers who devised the methodology. If for example, the methodology is an International standard it is considered highly credible. At the other extreme might be a method devised by a student.	Green	Green	Orange	Orange
Communication - Methodologies enable presentation of findings as an indicator/label rather than a report	Green	Green	Green	Green
Enforceability -Ease of methodology to be verified by a third party in the context of a mandatory label	Orange	Red	Red	Red

Green: methodologies are available and strong
Orange: Some methodologies are robust enough, but most still require further development
Red: No clear methodologies available, further development required.

As carbon foot printing is the most advanced of the four impact areas there is the potential that this could be introduced as a good and simple proxy of a product's impacts, and may represent the next logical extension of the current energy label used within Europe. The drawback is that this would not necessarily provide a fully balanced description of the impacts of a product, and there remains the risk that some significant aspects of a product might be missed, particularly water eco-toxicity. An

5 http://www.developpement-durable.gouv.fr/National-experimentation-for-the

alternative approach would be to adopt a multi criteria method capable of determining all four indicators. This would mean further development of methodologies such as the BP X30 323 or the Product Environmental Footprint. The work being carried out by the French Government on the nationwide product labelling experiment should be evaluated further by the Commission to draw out and understand the key findings and lessons learnt from those participating in the experiment. However, ahead of implementing such dramatic changes there is a need to better understand the cost of implementing such changes to a mandatory label, in terms of developing and standardising methodologies, policy development, compliance as well as the burden ton manufacturers to achieve compliance. Manufacturers are under growing pressure to provide products with increasing information and labels around the world using different compliance standards due to the flourishing field of environmental indicators and numerous initiatives are being developed within countries. The Commission would benefit from ensuring that businesses are not burdened by having to comply with numerous schemes setting different requirements for their products. There has to be a cost benefits analysis performed to ensure that the cost of such changes don't outweigh its benefits.

Creating a clear Format for a New Label

As important as the methodology issues addressed above, there is also the need to create a new label format that can best display the additional information in a clear and understandable way for the consumer. The current energy label is well understood by consumers; is there a risk that by adding information to the label it will distract consumers from its primary focus, i.e. to inform on the energy efficiency of the products they are purchasing?

To investigate the above issue, two surveys were conducted; a qualitative survey (focus group) in Poland, Italy and the UK to test potential symbols and scales; and a behavioural experiment to test consumers' attitude towards the different type of labels and willingness to pay for environmentally better products, online in nine EU countries. The project did not aim at understanding which indicator(s) might be more important (i.e. is carbon footprint more important than toxicity) to the consumer when making a purchasing decision. The results of the qualitative survey emphasised the lack of understanding and miss interpretation by consumers of some of the new proposed symbols. In particular the eco-toxicity symbol was not well understood, and the resource efficiency one was often mistaken for recycling (because of the arrow) or distance travelled by a product (i.e. how far the product travelled to the retailer). As a result of this qualitative survey, both symbols were reviewed and changed to the symbol presented in Figure 5. The focus groups also tested three formats for the rating scale: stars, drops, and just letters as shown in Figure 6. The main comments gathered on the star rating indicated some confusion over whether the number of stars indicated a positive or negative performance (e.g. do 7 stars for Eco toxicity mean this product causes a lot of harm to the environment or little harm?). The use of different colours across the scale was felt to add to the confusion, rather than help clarify the meaning of the scale. In the case of drops rating (the second label in Figure 5), this was the least preferred option. Respondents were not sure what the letter stood for, as there was no scale of reference. Generally respondents could understand that A was better than B, but could not tell how wide the scale was (unlike the star or letter rating which show how many stars a products can get or the range of letters). The preferred scale was the letters' one, it was the easiest to interpret across all markets. The scale has a clear frame of reference with the letters A-G, and respondents thought it was clear that the bigger letter represents the product rating. The letters were seen as mirroring the energy efficiency rating scale. However, there was some confusion as to why the two scales were not made to match exactly (i.e. A+++ - G). Overall, having only the applicable letter in coloured font was deemed to be preferable, as per the third label in Figure 5. It was acknowledged across all markets that more information would need to be provided in order to understand the environmental performance symbols. This information should include the definitions, and could be provided through a combination of support via the internet, advertising campaigns and shops displays.

The concept of consumers being provided with information about the environmental impact of a product throughout its *lifecycle* was unfamiliar. This led to some confusion about the meaning of the labels. For instance, some participants did not understand why a symbol depicting a water footprint would be displayed on the label for a light bulb. The analysis identified that consumers who correctly identified the definitions of the new lifecycle performance symbols displayed more willingness to make environmentally favourable product choices. This was true for both the proposed Energy and Carbon Footprint Label and the proposed Energy and Environmental Label. The willingness of a responder to pay for "good" products increased as their understanding increased. Both of these points demonstrate that a consumers understanding of the symbols included on the proposed new labels is critical.

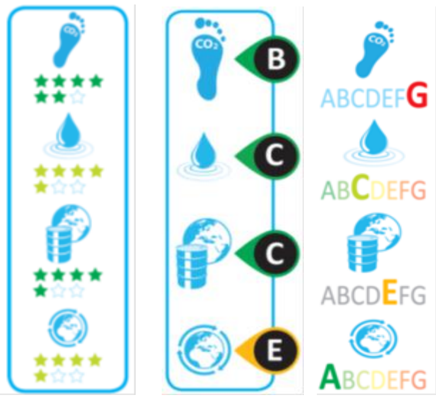

Figure 6: Different performance rating scales, left to right 'stars', 'drops', 'letters'.

Would consumer pay more for environmentally better products?

The behavioural experiment ran online across nine EU countries, testing 6,000 participants in an on-line auction to identify their willingness to pay extra for more environmentally friendly goods. Participants were divided into three groups depending on the level of information they were provided with around the labels: the first group was provided with no information; the second group was given the definition of the symbols; and the last group received a detailed explanation. Respondents were each faced with very different products to identify what drives a consumer when making purchasing decisions on certain products. The products were a washing machine - a necessity, and an expensive product to buy; a television - a luxury item, with a very wide range of product features and prices; and a light bulb - a necessity but an inexpensive product. It is worth noting at this stage that generally consumers will have a pre-existing list of parameters and product features that inform their purchasing decisions at the point of purchase. Within this, energy efficiency was identified to be considered relevant to consumers for the purchase of a washing machine but not for the purchase of a light bulb. The respondents appeared to be fairly pro-environmental as more than three quarters agreed with the statements, "I can personally help to reduce climate change by changing my behaviour" (77%) and "Even if others don't do the same, it's worth me doing things to live a sustainable lifestyle" (80%).By contrast only 15% agreed that "the effects of climate change are too far in the future to really worry me" and almost a quarter (24%) agreed "it's not worth us trying to combat climate change, because other countries will just cancel out what we do". The results suggest that it is not only climate change which is of concern to these respondents: three quarters (76%) agreed that the "earth has very limited room and resources" compared to only 9% who disagreed.

During the focus groups respondents were more concerned by the cost of running a washing machine, which is seen as a high energy using product, than the cost of using a light bulb, hence a more efficient washing machine was considered to be significantly less expensive to run. It was also identified that other product features where more important than the energy rating, so even for a washing machine for example, factors more important than energy efficiency included the wash capacity, the available programs, and the spin speed and so on. During the experiments conducted here product specific information (e.g. noise, spin speed, capacity, size of the screen and so) were held constant, so the focus of the experiment was on the impact of introducing *additional* environmental performance information to the current energy label.[6] The behavioural experiment did of course make the environmental label compete against price which is known to be a key determinant of product choice, but in reality, the environmental label would also have to compete with many other product features.

The use of both the proposed Energy and Carbon Footprint Label and the Energy and Environmental Label showed that respondents were willing to pay more for products than when they were only shown the current energy label as shown in Table 3l As all other characteristics of the products remained constant, this fully demonstrates that consumers are prepared to pay more for environmentally preferable products. However, comparing respondents' willingness to pay when they were presented with the proposed Energy and Carbon Footprint Label and then the proposed Energy and Environmental Label, showed that respondents were not willing to pay much more, so they did

6 This was also a pragmatic choice to allow us to implement the experiment within the time-limit for the online experiment and survey.

not distinguish between the Carbon Footprint Label and the additional three further environmental parameters on the Energy and Environmental Label.

The methodology review showed that the carbon footprint can be a good indicator of the overall environmental impact for specific product categories. The evidence of consumer behaviour here appears to support the approach of presenting just the carbon footprint as the additional information on the product label. This was further emphasised by the focus groups' findings, which concluded that consumers tend to focus on product performance which are already displayed on existing product labels (for instance, screen size for televisions or per cycle water use for washing machines). These product characteristics very clearly represent private gains to the consumer as they directly impact the user in terms of product experience and the cost of running the product. Overall, therefore, the focus of attention for many consumers is likely to be on the product characteristics displayed at the bottom of the label rather than the new symbols being added to the right hand side of the label. As mentioned before respondents were willing to pay more when the carbon footprint symbol was introduced, but increasing the number of additional symbols to the four environmental symbols did not increase willingness to pay further. This clearly demonstrates that consumers' choices can be affected by adding a carbon footprint symbol to the current energy label; however a key driver of purchasing decisions is still likely to be the product performance characteristics.

Table 3: Willingness to pay a premium for products carrying the proposed Energy and Carbon Footprint Label or Energy and Environmental Label (average across all respondents)

	Energy and Carbon Footprint Label		Energy and Environmental Label	
Product category	**Share willing to pay a premium for "better" product[1]**	**Minimum average premium they will pay[2]**	**Share willing to pay a premium for better product[1]**	**Minimum average premium they will pay[2]**
Washing Machines	39.8%	€ 64.19	39.3%	€ 65.08
Televisions	36.8%	€ 64.00	39.1%	€ 65.29
Light bulbs	50.2%	€ 0.47	45.8%	€ 0.46

Finally the experiments revealed that there are relatively few other consistent drivers of consumer purchasing decisions. It was hypothesised that respondents with pro-environmental attitudes would be willing to pay more for environmentally friendly products. However, the experiment did not provide strong evidence for this. It was also hypothesised that respondents from markets with an extensive history of environmental product labelling would choose, and be willing to pay more for, environmentally friendly products. Again there was no evidence for this in the results of the experiments. The key conclusion from the experiments was that there is evidence to suggest that a new energy label incorporating further environmental performance symbols could have a positive impact on consumer purchasing behaviour. Overall consumers demonstrated that they had a willingness to pay for more environmentally preferable products affixed with the proposed new labels.

Conclusion

This work investigated two aspects of extending the scope of the current product label used in Europe. The first was a review of whether it was technically feasible to extend the scope of the label to encompass energy and carbon, or energy and environmental aspects. A review of the existing methodologies, tools and information showed that this would be feasible, particularly for carbon and for water footprints, as these are the more developed areas. Use of the resource efficiency and water eco-toxicity footprints, while possible, would require significantly more development work as they are less well developed in the public domain at present. The second aspect of this work explored whether consumers would engage with should further information be provided, whether it would influence their purchasing decisions. The results show that consumers would be influenced by further information, and would be willing to pay more for the product that was "greener". However, environmental considerations come into the purchasing decision only after other aspects have been addressed. So in the example of a washing machine, environmental concerns would be considered after the wash capacity, spin speed, wash setting, noise have been taken into account. The results show that consumers are potentially willing to pay more for a product that has better environmental credentials; although, the distinction between the Energy and Carbon Footprint label, and the Energy and Environmental Footprint Label is practically non-existent (Table 3). This clearly indicates that consumers are unable to distinguish an array of indicator and would favour just one additional indicator. Whether this additional indicator should this be a carbon inductor or an overall environmental score was not tested within this work.

The ultimate value of this work is combining the two aspects of a potential label extension, to understand whether this would deliver additional energy and environmental savings through further informing consumers' purchasing decisions at the point of purchase. The conclusion is that the energy label could be technically extended, and that consumers would respond to this additional information to some degree, likely delivering further energy and environmental savings. But, consumers are unlikely to respond to the full information, and the response to the mid-level of information (Energy and Carbon Footprint Label) was taken into account only after other factors – price and other features - had been taken into account. Hence attention needs to be paid to the value of extending the labelling scheme, and whether the increased amount a consumer is willing to pay will cover the increased costs to the manufacturers to achieve the declarations.

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Come On Labels - Supporting energy labelling of products by monitoring labels in shops, collecting information about tests, supporting surveillance, and promoting to consumers

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Abstract:

The Come On Labels project was organized between 12/2010 and 5/2013 and focused on the implementation of the energy labelling legislation in 13 European countries. The main project activities included:

- Overview of the national implementation of EU labelling legislation,
- Visiting over 900 shops to assess the proper display of energy labels at the points of sale,
- Collection and exchange of information about the product compliance verification activities through laboratory testing around the EU,
- Promotion of the energy labels to consumers, and
- Evaluation and monitoring of labelled product early and better replacement schemes.

This paper focuses on:

- Comparing EU legislation on energy labelling and ecodesign in terms of energy efficiency classes created in each product specific energy labelling scheme and actually existing on the market for the contemporary effect of the ecodesing requirements
- Monitoring the level of market surveillance activities in selected countries for energy labelling,
- Collected information about compliance verification tests within the project duration,
- The results of the shop visiting exercise that took place in 13 European countries:
  - 3 rounds of shop visits (spring and autumn 2012, spring 2013),
  - 20 shops at least in each country at each round,
  - Focus on all types of shops and labelled products.

1. Summary: main project findings and achievements

The Come On Labels project has been designed in 2009, before the new energy labelling legislation were put in place. When, starting from 2010, the new framework directive and the first product specific delegated acts were enforced for the major household appliances, TV and lighting the Project was in the unique position to be the right tool to support the proper implementation of new energy labelling schemes in 13 European countries. The project targets are market surveillance Authorities, retailers, suppliers and consumers.

Examples of the most successful activities include:

Working with market surveillance authorities:

Each EU Member State is responsible for organising market surveillance activities, ensuring that correct information is shown on the energy labels, and that energy labels are properly displayed in shops and other points of sale. However since the level of such activity in a number of countries is insufficient, the Come On Labels project has organised the following supporting actions:

- Two presentations to ADCO Labelling group and numerous individual cooperations on energy labelling market surveillance, related to label display and product testing,
- discussions and explanations aimed to reach a common understanding of the legislation labelling requirements, for example about the meaning of individual icons displayed on the label,
- clarification of the concept of “placing on the market and putting into service”,
- sharing the outcome of the shop visits and the found levels of proper label display, and hypothesising possible improvement activities,
- organising common training activities for national inspectors, or the market actors such as the retailers and suppliers,
- analysing the feasibility of product compliance verification activities through laboratory testing and best ways for sharing test results data among national market surveillance Authorities in the EU Member States.

Collecting and sharing data on product compliance verification through laboratory tests:

Testing products to verify the declarations on the energy labels is one of the key factors for ensuring that energy and resources savings foreseen through energy labelling are really achieved. Unfortunately, the number of product compliance verification testing is insufficient. The project is not expected to directly test products, but has given an important contribution in this sector through:

- collecting publicly available information about product tests results. Information on product testing in the EU (UK, The Netherlands, Sweden), as well as in Australia and USA has been collected, together with product testing activities of other Intelligent Energy Europe projects. All information has been summarised and circulated among stakeholders with the aim to improve the knowledge on the feasibility and affordability of product testing.
- Stimulating EU wide cooperation in product testing: While manufacturers test their product only once for the whole EU market, MSA usually refer to the models available on their national markets. The Come On Labels project has therefore prepared documents summarising the existing experiences in testing products in foreign laboratories, regular meetings of authorities to share experience, regional testing approach sharing the model names of products, and the examples of European projects. All these reports are aimed at making the EU-wide cooperation easier for national authorities.

Monitoring the label presence in shops[1]:

Energy labels can be a successful tool for consumers if they are properly displayed in shops. But how often and how correctly are labels shown in shops? The Come On Labels project has organised three rounds of shops visits, each time visiting around 300 shops, monitoring the presence of energy labels per shop type and product type. Outcomes include:

- Monitoring the label presence per shop type and evaluating possible improvements for shop types where correct label display is lower: kitchen studios, individual retailers, and general hypermarkets,
- monitoring the label presence per product type, showing a lower percentage of labelled model for wine appliances, air-conditioners and electric ovens and the increasing percentage for TVs,

[1] http://www.come-on-labels.eu/displaying-energy-labels/status-of-appliance-labelling

- evaluating the effect of new energy labels, already displayed in 2012 on more than half of the models, to lower the amount of incorrect labelling, since the new energy labels are printed in one part only.

Retailer training manual[2]:

In order to improve the level of label display in shops, the Come On Labels project has prepared a retailer training manual aimed at educating shop assistants on the proper label display. The manual, available in 11 languages and 13 country adaptations, summarises the legal requirements of product labelling, explains the marketing importance of label display, shows examples of correct/incorrect label display in shops, and gives concrete advice which the shop assistants can give to customers. The training material has been:

- Circulated to individual market surveillance authorities´ inspectors
- Used in individual retailer training seminars for retailer chains and shops
- circulated to shops via national CECED manufacturers´ association members
- Disseminated at conferences and events for market actors.

Dissemination to consumers and end-users[3]:

Purchasing decisions by consumers influence the energy consumption of installed products for many years ahead. Therefore consumers are the primary target for energy labels. But consumers have to be fully aware about energy labelling and understand the content of the single products label. Consumer awareness and label understanding has become more important with the introduction of new energy labelling. The Come On Labels project has organised a number of activities for better consumer awareness:

- Numerous press releases and articles in general media – over 170, with a readership/viewers of over 3,3 million,
- preparation of leaflets, brochures, posters, or bookmarks and distribution to consumers via shops, information centers, energy agencies, libraries, etc., - over 580 pieces printed,
- Organisation and participation to events, seminars, fairs and exhibitions, explaining the energy labels to visitors and participants.

Comparing energy labelling with ecodesign requirements[4]:

Energy labels were designed to help consumers to choose more energy efficient products at points of sale. Energy class A has been for long time the best energy efficiency class. However due to the technological development, the introduction of the three new A+/A++ / A+++ classes and the contemporary enforcement of the ecodesign requirements, class A is in a number of cases only the least available energy class on the market. The Come On Labels project has therefore produced a paper, summarising the range of energy classes displayed on energy labels and the effect of the enforcement of minimum ecodesign requirements. This paper has been circulated among national authorities and market actors, to explain the energy efficiency classes available on the market for individual products.

[2] http://www.come-on-labels.eu/displaying-energy-labels/retailer-training-manual
[3] http://www.come-on-labels.eu/promoting-energy-labels/examples-of-promotion-activities
[4] http://www.come-on-labels.eu/legislation/eu-product-energy-labelling

Product group		Energy efficiency classes shown on the energy label	Energy efficiency classes allowed on the market by minimum ecodesign requirements	Energy efficiency classes shown on the label, but not allowed by minimum ecodesign requirements
Washing machines		A+++ / D	A+++ / A	B, C, D
Dishwashers		A+++ / D	A+++ / A	B, C, D
Refrigerating appliances	Compression type	A+++ / D	A+++ / A+	A, B, C, D
	Absorption type	A+++ / G	A+++ / E	F, G
Televisions		A / G	A / G	
Light sources		A / G	A / C	D, E, F, G

Due to the complexity and the multiple actions of the project it is impossible to give a complete summary of the outcome in this paper. Therefore in the following paragraphs only three tasks will be described in detail: the implementation of the energy labelling and ecodesign legislation in EU Member States, the shop visits for monitoring label presence and the overview of product testing.

2. Energy Labelling and Ecodesign legislation implementation

While organising the project activities, such as visiting shops monitoring the presence of energy labels, collecting information about the product testing activities, disseminating energy labels to consumers and evaluating experience about product replacement schemes, one of the key features of the Come On Labels project activities in all of its 13 participating countries[5] was a regular contact with the national Market Surveillance Authorities, as well as other key national stakeholders, such as government representatives, manufacturer and retailer associations, etc. All of the project achievements, such as an overview of the presence of labels by the types of products and shops, or the examples of product tests, have been negotiated, with the aim to improve the quality of market surveillance activities, and thereby the level of product/shop compliance and consumer satisfaction.

One of the specific product project outcome was a detailed review of the level and nature of activities undertaken in individual project countries[6]. Find out here examples of some of the activities described in the main deliverable – only covering countries participating directly to the project:

A positive example of an increase of the level of surveillance activities came from the **Czech Republic**, which has in the past visited only limited number of shops, to verify the presence of energy labels, eg. 4 in the year 2010. In the year 2011 this has increased to 18 shops surveyed, and in 2012 to close to 300 shops. Overall results have been published in a press release. Authority representatives confirmed, to maintain this level of shop visits also for the future periods.

[5]Austria, Belgium, Czech Republic, Croatia, Germany, Greece, Italy, Latvia, Malta, Poland, Portugal, Spain, UK

[6] Those interested in more information on related topics, may also consult another IEE projects: ATLETE II, focusing on market surveillance activities, by a questionnaire, mainly related to washing machines: http://www.atlete.eu/2/market-surveillance-authorities and Ecopliant project, focusing on ecodesign related activities: http://www.ecopliant.eu/activity-streams/work-package-2-establishing-best-practice/ .

Austria reports 70 shop visits per year, with last year identifying 70 products not being labelled. This level of shop surveillance is considered by the authorities as sufficient and does not expect more controls in the future. No product testing takes place in Austria, but active participation to ADCO labelling group is confirmed.

In **Belgium**, 1,3 full time staff equivalent work at the ministry responsible for the legislation adaption and inspectorate responsible for its implementation, and 0,2 full time equivalent responsible for energy labelling related ecodesign and environmental product issues. In 2011, some 202 shops have been surveyed, and 3330 products declared as non compliant out of almost 20 thousand surveyed. 46 products have been tested in the last 4 years (2009 – 2012), mainly light sources, refrigerators and dishwashers, no sanctions have been applied, some lamp manufacturers have adapted the product packaging. Testing three units of the Step 2 is considered as one of the most prohibitive reasons for not conducting more product tests, and for the future foreign laboratories are expected to be able to submit tender applications.

The situation in **Germany** is more fragmented, since the surveillance activities take place by individual federal states. The recast of the German legislation on labelling, as a reaction to the EU Energy Labelling directive recast, has strengthened the role of market surveillance, eg. by introducing the requirement to set up a market surveillance plan, and reporting requirements. An example from the federal state *Hesse* includes a cooperation between the authorities and retailers, not only in ensuring correct labelling but also actively promoting efficient appliances. In *Bavaria*, laboratory testing of LED lamps is envisaged for 2013, related both to the energy labelling and ecodesign requirements. *Rhineland-Palatine* reports on 211 shop visits (including both first-time and follow-up visits) and 18 cases of administrative fines conducted. Baden-Wuerttemberg focused on a agreement between the federal state´s ministry of environment and the local authorities, including a specific target for conducting market surveillance and establishing a management system comprising both labelling in shops and product testing. Results of activities are shared on a national level in the Bund-Länder working group, and internationally within the ADCO group on market surveillance.

The **Italian** surveillance authority is planning to implement a programme of checks on lighting products in the period 2013 - 2014 as part of a Memorandum of Understanding with the Italian Union of Chambers of Commerce, in cooperation with the chambers of commerce in the area, which includes the inspections of manufacturers and distributors as well as carrying out tests in selected laboratories. In general it is expected that suppliers must provide the technical documentation of the controlled product and, in case of doubt, the demonstration of compliance through the results of laboratory tests.. The monitoring costs are borne by the Authority. While few product tests take place in Italy, for 2013-2014 about 70 light sources are planned to be tested. As for the cooperation and international information exchange opportunities, Italian representatives appreciate the co-funding of market surveillance actions by the EU programmes and the European Commission offer of both financial support and the opportunity to meet with other Authorities and related institutions to share experience, compare procedure and when possible results. Also, EU centralised market surveillance actions and studies, developed by the European Commission such as the 2008 shop survey, or the funding of Round Robin test are welcomed.

One of the countries where little labelling compliance verification activities take place is **Latvia**, where no product testing and limited shop visits take place. However, Latvia can benefit significantly from the international cooperation. The ´Nordic project´, focusing on market surveillance of the Nordic countries, also invites Baltic countries for cooperation and Latvian authority has confirmed its interest to receive the results and learn from its best practice.

The legislation in **Malta**, for example, includes the right of the Technical Regulations Division to request technical documentation in electronic format from suppliers within a specific timeframe and in case of potential and actual non-compliance cases, to order the supplier to forward the evidence concerning the accuracy of the information supplied on their labels or fiches and take the necessary preventative steps to ensure compliance. Some 20 formal shop visits took place in 2012 and 20 are planned for 2013, and while no formal fines have been issued, information meetings and retailer trainings have been organised to inform non-compliant shops about their obligations related to energy labelling. No product tests take place, with one of the arguments being the lack of national accredited laboratory, but an interest in international exchange of experience and best practice was confirmed.

The last country to fully transpose the Energy Labelling directive has been **Poland**, which was officially and publicly urged by the European Commission to adapt it. The legislation was issued in September 2012 and entered force in Poland on February 1st, 2013. Two organisations are responsible for the market surveillance, one for all energy related products except TVs, and one for TVs only (and other electronic equipment for other surveillance matters). Due to the late approval of the legislation, no formal shop visits and product tests have yet been reported. A plan for testing 12 products has been announced for 2013, but the product categories have not yet been selected. Lack of financial resources and other priorities (dangerous products) are reported as the main barrier, but also an interest for international projects and active sharing and adaption of best practice.

United Kingdom is one of the EU countries, conducting regular product testing and shop surveillance visits. Its Advertising Standards Authority is also responsible for advertising and distance selling requirements. The approach of the National Measurement Office is to combine market surveillance with business support in order to increase compliance. In 2012, 188 retailers were visited, with average compliance over 70%, and 28 thousand products captured with over 60% compliant. Shops with a non-compliance rate of 50-100% products displayed were revisited, others received immediate advice followed by a letter requesting evidence of compliance. As regards product testing, the overall review of activities is not known, individual cases have been published in the form of press releases. The Energy Saving Trust, voluntary scheme covering 20% of the top energy efficient products, carried out 15 tests in 2010-2011 and 9 tests in 2011 – 2012, results of which have been discussed with the suppliers.

3. Shop visits

The proper presence of energy labels at the point of sale, or specific information on catalogues and for internet sales, is crucial to allow consumers to make an educated choice of their new appliances.

The experience shows that the presence of labels on appliances in many shops is in general high around the European Member States; however, significant problems still exist in relation to specific product groups or distribution channels.

The Proper position of the label according to the EU legislation is shown in Table below.

Internet sites and mail order catalogues check: It is important that customers unable to see the product (and therefore the label) displayed are provided with the essential information of the products before the purchase. Internet sales and mail order catalogues check can be approached in the same way as shop inspections. The list of information to be checked is included in the product specific implementing measure.

Checking of product advertisements: According to the new energy labelling framework directive any advertisement for a specific products shall contain the energy efficiency class, if energy-related or price information are disclosed. Therefore, one of the market surveillance actions is also to verify if the energy class is always properly mentioned on the advertisements.

Table: Proper position of the label according to the EU legislation

Appliance	Position
General	In the clearly visible position specified in the relevant implementing directive or regulation
Refrigerators, freezers and their combinations	The label shall be placed on the outside of the front or the top of the appliance, in such way as to be clearly visible
Washing machines	
Dishwashers	
Televisions	On the front, in such a way as to be clearly visible
Tumble driers	On the outside of the front or the top of the appliance, in such way as to be clearly visible, and not obscured.
Combined washer-driers	
Air conditioners	
Ovens	On the door (outside) of the appliance in such way as to be clearly visible and not obscured. For multi-cavity ovens, each cavity shall have its own label, except a cavity which does not fall within the scope of the harmonized standards.
Lamps	The label shall be placed or printed on, or attached to, the outside of the individual packaging of the lamp. Nothing else shall obscure it or reduce its visibility.

3.1 The shop visit methodology[7]

Within the Come On Labels project, 3 rounds of shop visits have taken place between December 2011 - January 2012 / August - September 2012 / and January - February 2013. The shop visits took place in 13 European countries and each partner visited at least 20 shops at every round of the shop visits. The check of the correct label presence in the shops within the Come On label project should follow the same procedure for every visit in order to make inspection results comparable.

The formal procedure for each shop visit includes three steps: preparation, inspection and follow–up. The label display for each model of the investigated products should be recorded following the check list and the shop should be informed about the next steps that the national Authority would be intending to take after the conclusion of the inspection. The follow-up depends on the verification procedure established in the national legislation.

In total, within the project, 900 shops have been visited, on average 300 shops per shop visit and 23 shops per country. The following types of shops were monitored:

[7] http://www.come-on-labels.eu/displaying-energy-labels/appliance-labelling-in-shops

- **Electronic superstores:** Large-scale specialists offering electrical appliances with a broad product range and often specialised departments for the different product groups.
- **Electric specialists:** Small and medium enterprises usually with a large range but a limited display area; often combined with service and maintenance offers.
- **Kitchen/Furniture stores:** Offering kitchen furniture including major household appliances; high degree of competence in planning and consulting services for clients; usually selling complete kitchens with most common major electrical appliances mainly of the built-in type.
- **Hypermarkets/Cash and Carry:** In most Member States, these are not as important for the sale of large household appliances as the other channels because the self-service character of these shops often does not respond to customers need for advice at the purchasing time.
- **Mail order and internet stores:** Based on websites and catalogues which are increasingly important for the sales of major domestic appliances. Information from the label and product fiche is displayed, often by text, not necessarily as a picture of the label.

Each country could select between two options for the selection of the range of shops covered:

- **Random selection:** in a selected town, region or country, making sure that each type of shops are represented. Within the random selection, some countries focused primarily on the retailers representing highest national sales.
- **Potentially "problematic" types**: the majority of shops covered are the ones expected to have lower presence of labels – in general or for certain type of shops.

It is worth noting that the overall results of this exercise are not representative of the market for the EU and for individual countries, but only indicate some trends and identify some of the problems.

Project partners have monitored all products covered by the old and the new energy labelling scheme:

Appliances with a "new label":
- Washing machines
- Dishwashers
- Refrigerating appliances including wine storage appliances
- Televisions.

Note: TVs and wine storage appliances have been included in the calculations, even though some of the products may have entered the market before the labelling requirement entered into force in November 2011.

Appliances with the "old" energy label:

- Tumble driers[8]
- Electric ovens
- Air conditioners[9]
- Household lamps.

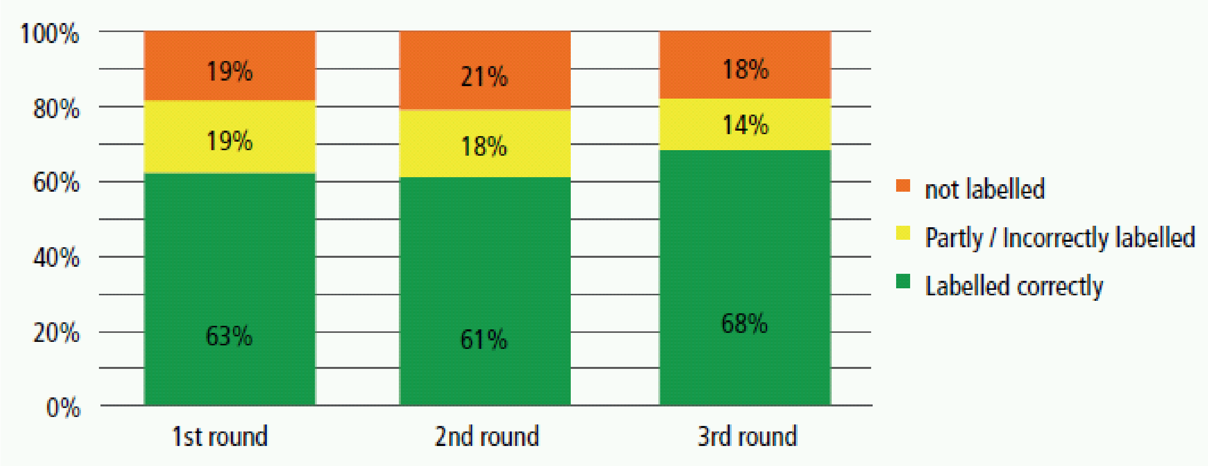
Light sources are not covered in the shop visit, since the label is printed on the package directly and therefore does not have the same potential label display problem as the other products.

[8] Voluntarily the new label can be used since May 2012.
[9] The new label is mandatory from 1 January 2013, but could be displayed before on a voluntary basis. This fact was reflected in the monitoring.

3.2 Summary of findings of the proper presence of energy labels in shops

The overall result of the shop visit exercise is that between the late 2011 and early 2013 a **slight improvement** of the presence of energy labels at the points of sales has been occurred.

Figure: Share of proper label display in 1st, 2nd and 3rd round of shop visits per products



One of the main explanation, as shared by project partners, is the increased use of the new energy labels. The reasons for that are:

- The new energy label is only circulated in one piece which reduces the possibility of wrong label display
- Due to the new design and content there is a higher motivation of retailers to display label properly on products
- Organisation of a number of promotion activities increased the attention of consumers towards the labels
- Within the market surveillance activities, some authorities and other organisations increased the level of activities related to label display.

The Come On Labels project also monitored a "**partial/incorrect label**" display (i.e. for example labels being printed in shops, black and white copies, "strip" displayed only, labels placed at the back or inside the appliance, etc). There are two contradictory tendencies influencing the label display:

- As mentioned before, new energy labels are improving the situation reducing the opportunities for retailers to display only part of the label,
- With the growing importance of products sold over the internet, internet shops often display only partial information from the labels. While the legislation specifies the list of information to be provided for each product type, internet shops often only publish main product features, but not all the requested information.

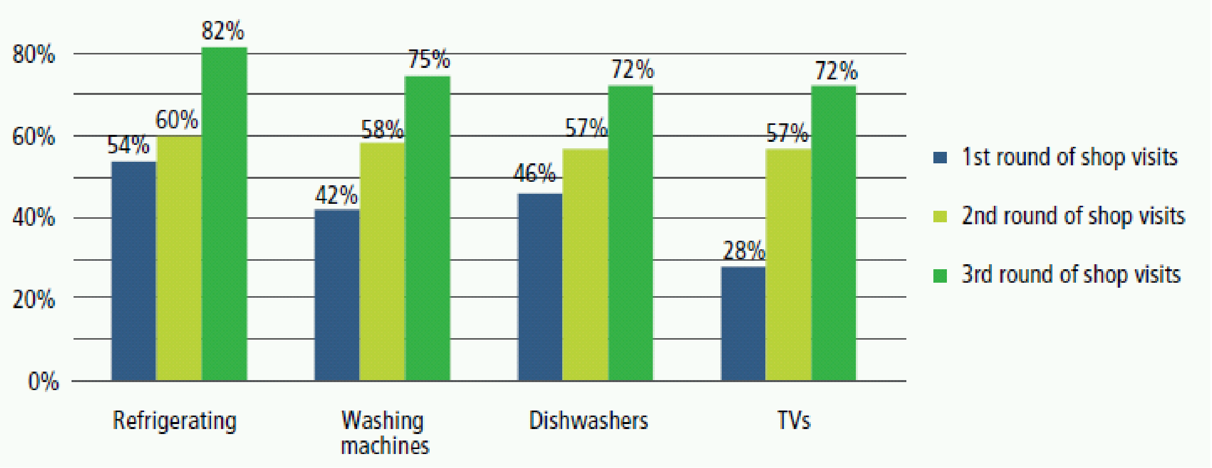
Within the project duration (12/2010 – 5/2013), the **new energy labels** have entered stores for the three types of white appliances (refrigerating appliances, washing machines, dishwashers), and TVs and wine storage appliances.

New energy labels for tumble driers, air-conditioners, non-directional light sources and lamps, were also enforced, but due to the later dates of mandatory application, and because the project partners were unable to gather the date of placing on the market of the single models the presence of the new label for these appliances have been monitored, but not statistically evaluated.

The new label display for refrigerating appliances has been most “successful”, where over 80% of appliances in the shops in early 2013 had already the new energy label – up from half of the products of about one year earlier.

Televisions are the product group being labelled in shops for the first time. While less then one third of models was labelled in early 2012, one year later over two thirds of models bore the label.

Figure: Share of the new energy label display per product category



On the contrary the following products were the most “**problematic**” in terms of the proper label display:

- Wine storage appliances: newly labelled product group, with a niche position and slow turnover in most markets, taking the least attention of the retailers and presumably also consumers,
- Air-Conditioners: sometimes distributed in other types of shops (installers shops) , where shop assistants are less used to display energy labels,
- TVs: A new product category, still showing a significant increase of the labels display, but with the date of market entry of individual products not possible to verify,
- Ovens: surprisingly this product category is often not labelled, even if ovens have had the label for a long time and are distributed in shops where other products are instead correctly labelled, and, moreover, large section of the market is listed as class A.

Table: Display of new energy labels in shops – Results per product type

	Labelled correctly	Partly labelled	Not labelled
Refrigerating appliances	76 %	14 %	10 %
Wine storage	34 %	8 %	58 %
TVs	57 %	10 %	33 %
Washing machines	73 %	15 %	12 %
Dishwashers	71 %	15 %	14 %
Air-Conditioners	28 %	32 %	39 %
Electric ovens	45 %	23 %	32 %
Tumble driers	58 %	24 %	18 %

When shop types are considered, the following ones are the most “**problematic**” in terms of the proper label display:

- Kitchen studios: since kitchen studios are specialised in furniture selling, many shop assistants do not use labels on purpose, arguing that the labels destroy the design of the kitchen furniture displayed
- General hypermarkets: since general hypermarkets focus on a large number of items, labelled products are only one (sometimes very small) part of their portfolio.
- Electric specialists: despite focusing mainly on electric products, these are individual shops (not chains) and the level of proper label display ranges considerably here, from almost 100% compliance to a very low level of label display, depending on the shop manager decisions.

Table: Display of energy labels in shops – Results per shop type

Shop type	Count	%	Labelled correctly	Partly / Incorrectly labelled	Not labelled
Electronic superstore	73	24%	70%	9%	21%
Electric specialist	126	30%	56%	12%	31%
Kitchen studio / Furniture stores	58	24%	26%	15%	59%
General hypermarkets / Cash and Carry	47	14%	50%	8%	37%
Mail order and internet stores	27	8%	54%	35%	11%
Total - Visits 3	279		51%	13%	35%
Total - Visits 2	331		52%	11%	38%
Total - Visits 1	290		54%	13%	33%

3.3 Example of labels not correctly displayed

The most common examples of labels not being correctly displayed include:

- Labels covered with other stickers, advertising materials, or price tags
- Labels placed inside the appliance, on the side or on the back
- “DIY” labels, hand written labels made by retailers
- Labels sealed in a plastic envelope, not accessible to consumers in shops
- For old labels – only the data strip is displayed / or only the background with the coloured arrows but with no figures
- Labels not matching the appliances
- Two labels for one appliance – in some cases also both the old/new labels, both showing a different energy class.
- For internet shops, some of the prescribed data is missing
- Usage of non-existing energy classes, such as A+++++ or A+++-20% in internet sales, where it is used as the energy class indication.

These and other issues have also been reflected in the project´s retailer training manual, which was then actively circulated around the shops, and which includes further sample pictures of wrong label placement.

Some of the shop visits were accompanied by informal interviews with shop assistants, seeking feedback on why labels were not displayed fully in certain shops or for certain products types. These interviews have been done on a voluntary basis – not as a formal project deliverable. Retailers have been, however, indicating the following reasons for not showing the labels correctly:

- The national system of the distribution of energy labels to shops influences the availability of labels.
- In countries, where labels are not distributed by supplier associations, the responsibility of individual suppliers to deliver the two parts of the old labels could be lower.
- Sometimes the energy label is sealed in a plastic bag, which neither the retailers nor the consumers want to open in the shop, since it could be perceived that the specific model is a used product, or that other parts included in the bag could be lost.
- Sticking a label onto the product could leave glue residues on the surface of the product, when the label is removed.
- The aesthetics of the labels on the products, mainly for built-in and in kitchen/furniture shops.
- The use of the shop’s or manufacturer´s own “eco” labels for retail stores. These labels, placed on selected products, are made clearly visible and are oft en part of marketing activities of the retail store. However, the criteria for selection are not always made available and in any case this behaviour is in contrast with the obligations of the retailers established in the energy labelling framework directive.
- Arguments of having no interest in labels, as if the label were simply a matter of choice.
- Slow turnover of some products, resulting in presumably old models being displayed that were placed on the market before the new legislation entering in force.
- Mandatory presence of energy class information generally unknown to managers of e-commerce shops’ general catalogue websites and in product advertising since this is a new provision.

- Claiming that a different legal entity is selling the products to consumers, than the one displaying the products in the shop.

4. Retailer training

To contribute to the improvement of the proper display of energy labels in shops, the Come On Labels project has prepared a Retailer Training Manual, summarising the following information:

- Explanation of the content and importance of energy labels
- Guidance on the proper label display
- Facts and tips on the labels and energy efficiency for consumers.

The document is available in 11 language and 13 national adaptations[10].

Over 1000 copies of the training manual have been printed and circulated, numerous electronic samples have been circulated to retailers, suppliers, authorities and other interested stakeholders. Examples of the usage of the document include:

- Retailers: Individual training sessions for shop assistants from individual shops and shop chains and Inclusion into retailers´ education and e-learning schemes
- Manufacturers: Common distribution of the manual to individual suppliers, either by individual manufacturers, or in cooperation with the national manufacturer association
- Authorities: Distribution to individual inspectors located around the country and organisation of common events and seminars for inspectors or the retailers
- Consumer NGOs etc: Common awareness raising about proper labels display

5. Examples of known compliance tests[11]

Energy labels are a crucial driver for market transformation, orienting consumers' choice towards more energy efficient appliances and thus realizing the potential of available technologies.

Unfortunately, not all EU Member States apply effective actions for controlling the correct labelling implementation. Without a concerted effort the same is likely to happen for the forthcoming eco-design and energy labelling implementing measures for energy using products.

The Come On Labels project therefore seek to collect information about product testing, undertaken in order to verify energy consumption related information on the product energy labels. This information is shared by the project partners in 13 European countries with stakeholders, such as national surveillance authorities, manufacturer and retailer representatives, consumer organisations, media, etc.

The main goal of this Deliverable was to increase European-wide implementation and control of energy labelling and eco-design implementing measures for appliances by:

- collecting and circulating results of the European testing results on household appliances;

[10] http://www.come-on-labels.eu/displaying-energy-labels/retailer-training-manua
[11] http://www.come-on-labels.eu/appliance-testing/appliance-tests-2011-2013

- contributing to increased the attention of the National Authorities through a better awareness of the impact of the energy labelling on the national energy efficiency;
- giving concrete guidance to EU and National Authorities for an increasingly effective labelling implementation;
- highlighting a shared procedure for the verification of the manufacturers' labelling declaration including referencing to a methodology for laboratories accreditation and models selection.

The Come On Labels project has focused on **The individual testing activities collected and explained in the three editions of this document include:**

- **ATLETE project, Intelligent Energy Europe project, 2009 – 2011**

The project has focused on testing refrigerating appliances for their compliance with the energy label declarations and it was the first European wide testing activity focusing on a EU policy measure concerning market surveillance and physically testing 80 randomly selected refrigerating appliances. The project has brought specific examples of product test results and confirmed the affordability of market surveillance.
The final test results show that 80% of appliances subjected to testing and for which testing has been concluded complied with the energy efficiency class declaration and the two related key parameters: energy consumption and storage volume. But when all five parameters are taken into consideration 57% of them do not comply with at least one of the tested parameters.
All test results and test reports for each individual model are publicly available on the project website and have been shared with the EU Member State Market Surveillance Authorities, media, experts and stakeholders.

- **UK - National Measurement Office, 2010 – 2012**

The National Measurement Office (NMO) tested refrigerators, fridge freezers and freezers across a broad spectrum of specifications for compliance against the EC regulation 94/2/EC for energy labelling accuracy and also EC 643/2009 for allowed energy use for household appliances.
Twelve models were purchased from on-line and high street retailers and sent to an independent accredited test house for examination. Four of them were subject to further testing to verify non-compliance. The four failed with a range of results requiring a range of investigation, enforcement action and sanctions. In the worst case, the test report identified the percentage difference between the measured and claimed energy consumption was over 120%, this would be the equivalent of claiming to be an A rating when in-fact the test results suggested a G rating.

- **UK – Energy Saving Trust 2010 - 2012**

The UK's Energy Saving Trust Recommended scheme (ESTR) voluntary product labelling scheme is an example of an Environmental Product Information Scheme encompassing its own compliance testing, enforcement activity and evaluation for environmental effectiveness and improvements in environmental quality.
In 2010-2012, EST tested 24 refrigerating appliances for the energy consumption and the storage volume, but not the other parameters of the energy labelling (storage temperature, temperature rise time and freezing capacity) to verify the (old or new) energy labelling declarations and the compliance with the ESTR minimum requirements (EEI corresponding to A+ class).
As far as the energy consumption is concerned, 4 models out of the 6 for which a Step 2 test (on 3 additional units of the same model) would have been necessary show a difference between the declared and the measured value largely exceeding the permitted tolerance of the relevant labelling scheme, while for other 2 models the difference is almost negligible.

- **Spain – IDEA tests, 2008 – 2011**

In Spain IDAE, the Institute for the Diversification and Saving of Energy, manages a national database efficient domestic appliances including the models eligible for the governmental rebate scheme. Compliance verification actions on the declared labelling parameters were run on these models according to the EU legislation and the relevant harmonised standards. IDEA acquires from the

manufacturer a sample of the product to be tested that is sent to LCOE (the Official Central Laboratory). In general, models selection is based on a higher probability of non-compliance.
It is worth noting that since only one unit of each model has been tested no formal conclusions about the compliance with the labelling declaration can be drawn from the test results.

- **Spain – ANFEL tests, 2010 - 2011**

The Spanish Association of Domestic Appliances Manufacturers, ANFEL, is active in supporting market surveillance by denouncing non-compliant household appliances and relevant suppliers. Examples of their activities include publishing the results of tests of two models of refrigerator-freezers, accused not to be compliant with the energy label declaration, requesting the national authorities and the national subsidy scheme organisers to remove these from the list of models eligible for the subsidy.

- **Nordic project: 2011**

Financed by The Nordic Council of Minister starting from 2011, the aim of the project is to develop the Nordic collaboration concerning market surveillance to check the accuracy of the information declared on the energy label and if the product fulfils the eco design requirements for Sweden, Norway, Denmark, Finland and Iceland.
Although limited additional information is available on the technical characteristics of the appliances tested, this is a good example on how test developed in one laboratory could be used as the basis for a market surveillance action in a number of EU countries.

- **The Netherlands: testing in German laboratory**

Another example of the successful use of test results achieved in a laboratory of a different country is included in the "Annual report 2009, Energy label compliance in the Netherlands". As reported, most of the tests on household appliances were done in the German laboratory VDE located in Offenbach. The testing of appliances followed a European procurement procedure, after which VDE Offenbach (and TNO Apeldoorn) were selected to carry out tests for 2009. On the basis of random sampling, several appliances from each category were tested to establish the level of correctness of information provided on energy labels. This example demonstrates the possibility of conducting testing in a cooperation between a MSA and laboratory from different countries.

- **Intelligent Energy Europe projects 2012 – 2014**

Several European projects are currently organised with the aim to verify energy consumption of certain products groups and to compare this with the energy label declarations, and / or the ecodesign legislation requirements. Currently (Spring 2013) these projects are:

- **ATLETE II**: 50 models of washing machines, full tests, including test reports, to be published in 2014,
- **Ecopliant**: product categories for testing to be decided, aggregated results expected in 2014,
- **PremiumLight**: focusing on high quality CFL and LED light sources, 60 – 80 models, test results expected in 2013-2014,
- **Euro Topten MAX**: high efficiency LED lamps, TV and tumble drier models, results in 2014,
- **MarketWatch**: product categories to be decided, based on non-compliance high risk suspicion, results expected in 2014,
- **ComplianTV**: 125 TVs and 75 monitors to be tested for energy labels and ecodesign compliance, results expected in 2014.

6. Conclusion

main aspects of the energy labelling implementation: from cooperating with the market surveillance Authorities, to the actual monitoring of the labels presence in shops and the collection of information about the presence of labels in shops, to the analysis of the potential of product replacement schemes and the monitoring of existing ones, to finally organising numerous dissemination activities.

Within the two main activities described in this paper, the project has concluded:

- Slight improvement of the presence of energy labels in shops, presumably mainly due to the increased presence of new energy labels,
- An interest of market surveillance authorities to exchange information about product testing and surveillance best practice, so that the authorities could learn from each other and benefit from their individual activities.

The sole responsibility for the content of this report lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the EACI nor the European Commission is responsible for any use that may be made of the information contained therein.

Come On Labels
www.come-on-labels.eu

Co-funded by the Intelligent Energy Europe Programme of the European Union

Evidence of Progress – Measurement of Impacts of Australia's S&L Program from 1990-2010

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Energy Efficient Strategies

Abstract

Australia first put categorical energy efficiency labels on residential appliances in the mid-1980s, and the first Minimum Energy Performance Standards (MEPS) for refrigerators was implemented in 1999. Updated in 2005, these MEPS were aligned with US 2001 levels. Considered together, these actions set Australia apart as having one of the most aggressive appliance efficiency programs in the world. For these reasons, together with good data on product sales over time, Australia represents a potentially fruitful case study for understanding the dynamics energy efficiency standards and labeling (EES&L) programs impacts on appliance markets. This analysis attempts to distinguish between the impacts of labeling alone as opposed to MEPS, and to probe the time-dependency of such impacts.

Fortunately, in the Australian case, detailed market sales data and a comprehensive registration system provides a solid basis for the empirical evaluation of these questions. This paper analyzes Australian refrigerator efficiency data covering the years 1993-2009. Sales data was purchased from a commercial market research organization (in this case, the GfK Group) and includes sales and average price in each year for each appliance model – this can be used to understand broader trends by product class and star rating category, even where data is aggregated. Statistical regression analysis is used to model market introduction and adoption of high efficiency refrigerators according to logistic adoption model formalism, and parameterizes the way in which the Australian programs accelerated adoption of high-efficiency products and phased out others. Through this analysis, the paper presents a detailed, robust and quantitative picture of the impacts of EES&L in the Australian case, but also demonstrates a methodology of the evaluation of program impacts that could form the basis of an international evaluation framework for similar programs in other countries.

Introduction

In attempts to address climate change and carbon emissions, Australia addressed energy efficiency improvements by first putting categorical energy efficiency labels on residential appliances in the mid-1980s[1]. Also promoting consumer information, this label uses stars to rate the energy efficiency of the product and promotes differentiation on the basis of energy and consideration of total life cycle costs. The original label, established in 1986, and its 2000 revision are illustrated below.

[1] Holt, S., Weston, J., Foster, R. (2011). The Australian Experience of

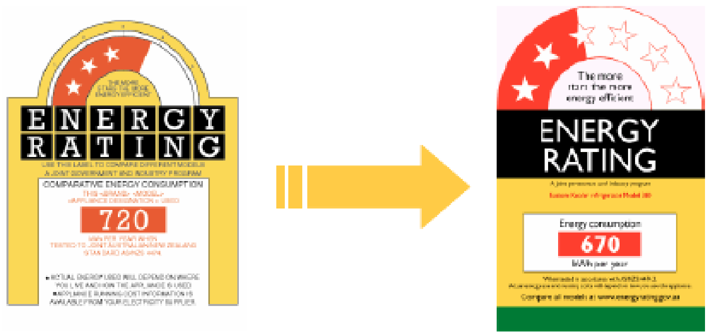

Figure 1: Original label (1986) and 2000 revision

The energy labels are simple but very salient for consumers, and now have extremely high recognition and credibility with consumers in Australia. This label was one of the first categorical labels for energy efficiency used in the world and the concept has now been successfully adopted in all regions, except North America. The goal of the Minimum Efficiency Performance Standards (MEPS) is to accelerate energy efficiency adoption rates for appliances in advance of what the market will otherwise deliver with energy labeling alone. Such standards were first implemented in Australia for refrigerators in October 1999, and later revised in January 2005. As mandated by the Australian legislature, MEPS allow the Australian government to prohibit manufacturers from selling their products if they do not meet the performance standards. In order to facilitate adoption of new more stringent standards, the 2005 MEPS were harmonized with the American 2001 standards, at the time considered to be the most stringent in the world. Around the same time, in 2000, the efficiency rating algorithm was rescaled to better represent the relationship between efficiency and volume and to deal with extensive “market creep” where large numbers of models had achieved fairly high star ratings in the 14 years since labeling began. Considered together, these actions set Australia apart as having one of the most stringent appliance efficiency programs in the world, along with the United-States and Canada. For these reasons, the Australian example represents an illustrative case study for energy efficiency standards and labeling (EES&L) program dynamics and how they impact appliance markets. This paper analyzes Australian refrigerator efficiency data covering the years 1993-2009.

Statistical regression analysis is used to model market introduction and uptake of high efficiency refrigerators according to logistic adoption model formalism, and thereby parameterize the way in which the Australian programs accelerated adoption of high-efficiency products and phased out others. Through this analysis, the paper demonstrates a methodology of the evaluation of program impacts that could form the basis of an international evaluation framework for similar programs in other countries.

History of Refrigerator MEPS and Labeling in Australia

The 1999 Australian MEPS were announced three years prior in 1996, and the 2005 MEPS was announced in 2001. A different approach for determining the standards was used for both the determination of the 1999 and 2005 MEPS levels: the 1999 MEPS levels were determined by using a statistical approach in which 1992 market data was used to evaluate the relationship between energy and adjusted volume of the appliance. The original approach sought to draw a line below 40% of available models in each of the nine refrigerator categories. However, this statistical method was replaced in 2001 with what is referred to as the “international harmonization” approach, in which the Australia MEPS were updated to align with American 2001 MEPS levels for refrigerators[2]. American MEPS levels in 2001 were considered to be the most stringent, and by adopting such standards, Australia eliminated trade barriers and set out to achieve ambitious energy efficiency goals. Meeting these goals was a remarkable achievement for Australia; in October 2000 not a single refrigerator or

[2] Holt, S., Weston, J., Foster, R. (2011). The Australian Experience of Minimum Product Standards.

freezer on the market met the proposed MEPS schedule which was intended to begin in 5 years[3]. A sparsely populated country like Australia is rarely in a position to unilaterally set MEPS to be the best in the world; it must rely on larger economic blocks like North America and Europe to invest the resources to push the market towards the technological limits, thus allowing smaller markets like Australia's to follow in their wake.

In addition to the new MEPS implementation approach, the energy labeling rating algorithm was re-scaled in 2000 for all labeled appliances (and again in 2010 for refrigerators, but the impact of this label change is beyond the scope of this paper). The original algorithm developed in 1985 and introduced in 1986, used an approach to calculating the star rating based on energy consumption and adjusted volume of the appliance. This method used a linear relationship that unfairly biased larger appliances and had a fixed energy step per additional star. The revised algorithm also calculates the star rating based on adjusted volume but with a fixed energy offset, removing some of the volume bias in the older scheme. The new scheme also introduced the concept of a geometric progression, which effectively fixed the percentage energy reduction per additional star to be constant across all star ratings (reflecting the fact that additional energy reductions are harder to achieve as absolute energy declines). The old algorithm had six possible star ratings ranging from 1 (worst performing) through 6 (best performing), while the new system retained 1 to 6 stars but included half star intervals (giving a total of 11 possible grades). The label itself was redesigned so the unearned stars were now visible in outline. As a result of the change, the star ratings prior to 2000 were phased out. However, the data used in this analysis solely uses the new algorithm, where data prior to 2000 was converted from the old algorithm to the new one. The consistent use of the new algorithm established in 2000 illustrates the evolution of domestic refrigerator technologies while labeling categories are held constant.

Methods

The Data

This paper analyzes Australian refrigerator efficiency data covering the years 1993-2009. Sales data was purchased from a commercial market research company (GfK Group) and the data was cross matched to a comprehensive registration database by Energy Efficient Strategies on contract to the Australian government as part of its ongoing monitoring and evaluation program. The purchased sales data includes sales by model and average price paid by model in each year. The registration database included all technical details for each model such as tested energy, volume, features, configuration and other critical data. Cross matched model data was then aggregated into product categories and star rating. While there are currently 10 categories of refrigerators and freezers on the Australian market (called Groups), this analysis focuses on the four categories of refrigerators described as combined refrigerator-freezers, which constitute approximately 80% of the Australian refrigerator market[4].

The data, used to evaluate the impact of the 1999 and 2005 MEPS, separated into 3 time periods delineated by the introduction of new MEPS.

- Period 1: 1993-1996
- Period 2: 2000-2003
- Period 3: 2005-2009

Statistical regression is used on the market share data of each star rating level for each time period to determine the rate of uptake of efficiency improvement. The regression parameters are then used in conjunction with the logistic formalism to develop S-curves representing the cumulative market share across efficiency levels.

The 1999 MEPS were introduced in the last annual quarter (October) and therefore the pre-1999 MEPS period is considered to be from 1993 through 1999. However, the 2005 MEPS revision occurred in January of that year, so the post-2005 MEPS period includes 2005 and is considered to

[3] Harrington, L., & Holt, S. (2002). Matching World's Best Regulated Efficiency Standards: Australia's Success in Adopting New Refrigerator MEPS
[4] Energy Efficient Strategies, 2010

be 2005 – 2009. One of the important observations of our research is that there was significant movement in the market in advance of the 1999 and 2005 MEPS as a result of announcements of the regulations in before their implementation. For this reason, market behavior in these 'transition periods' before each MEPS implementation date is not well described by an S-curve and therefore these years (1997-1999 and 2004) were excluded from the regression. The exclusion of the transition years is results in an increased R^2, confirming the rationale for their exclusion.

The Market Share Model

Original Market Share Data and Cumulative Market Share

The data includes sales and average price in each year for each product category and each star rating, which ranges from 1 to 6 stars in half star intervals. This data was used to obtain the market share percentage in each year of each efficiency rating. The market share percentage for each efficiency level indicates the percentage of the Australian market for residential refrigerators of each efficiency level. For example, if a 4-star refrigerator has a market share of 15% in 1993, this means that in 1993 4-star refrigerators only made up 15% of the total residential refrigerator market in Australia.

For this analysis, the cumulative market share across efficiency levels is used as the principal variable to evaluate the impacts of changes in efficiency over time. This cumulative market share of a specified efficiency level represents the additive value of the market shares of all of the star ratings equal to or greater than the specified star rating. For example, if the cumulative market share in 1993 for a 3-star appliance is 3.4%, than all appliances rated 3.0 or greater constitute a combined market share of 3.4%. The cumulative market share across star efficiency levels appears to be the best metric to evaluate the energy efficiency improvements because energy efficiency technologies that are used in one level are assumed to apply to higher levels as well[5].

Model Formalism

The general form of the cumulative market share relationship with time follows an S-shaped sigmoid function and is best described by the function expressed below[6]:

$$F(t) = \frac{1}{1 + e^{-q*(t-t_0)}}$$

- where *F(t)* indicates the cumulative market share of a specified efficiency level for a specific year, *t*;
- t represents the year of the market share data;
- t_0 is such that $F(t_0)$ = 0.5;
- and *q* is the adoption rate of a specific efficiency level.

This analysis uses the logistic model because it can easily be converted to a linear function, allowing for a linear regression analysis of the data and determination of the model parameters[7]. By definition, the logistic function has a maximum of 1, at which point market saturation is reached. The minimum of the function is 0, at which point the product has no share of the market. While the function has several parameters, those determined by the statistical regression are *q*, the rate of adoption, and *c*, the constant of the regression. The remaining parameters are functions of those determined by the regression.

[5] Van Buskirk, R. (2012). *An Adoption Curv-Fitting Method Estimating Market Efficiency Improvement and Acceleration*
[6] McNeil, M., & Letschert, V. E. (2010). Modeling Diffusion of Electrical Appliances in the Residential Sector
[7] Van Buskirk, R. (2012). *An Adoption Curve-Fitting Method Estimating Market Efficiency Improvement and Acceleration*

Analysis of the Data

The data is linearized to facilitate estimation of the cumulative market share with a function that can be estimated linearly. The linearization allows regression analysis to be performed and to estimate the values of the parameters *q* (the slope) and *c*, the constant.

A plot of the raw, untransformed cumulative market shares is provided below. The data used for the remainder of the analysis was rescaled using the logistic distribution described above.

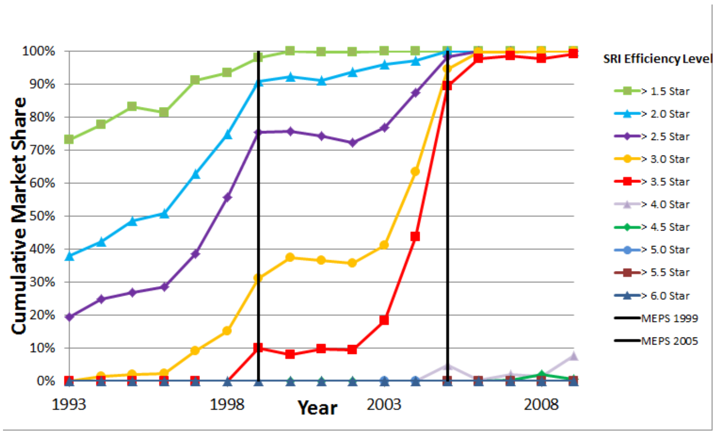

Figure 2: Raw Data of Cumulative Market Share of Australian Refrigerator-Freezers

Estimation of Model Parameters: q and t_0

In order to fit the data a regression is performed for each year on each of the 3 segments of the data delineated above to determine the slope of the trend line. The slope of the regression, representing the rate of adoption of new appliances, is represented by *q*. While the constant *c* does not appear as a parameter of the model, it is used to determine the value of t_0, the year at which the cumulate market share is 50% (i.e. the inflection point of the S-curve). Following from the fact that t_0 is such that $F(t_0) = 0.5$, we find that $t_0 = \frac{-c}{q}$.

Table 1: Summary of Regression Parameters and Statistics

	SRI EFFICIENCY LEVEL										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
VALUES OF q											
Period 1	-	0.17	0.19	0.16	0.19	-	-	-	-	-	-
Period 2	-	0.81	0.25	0.01	0.04	0.28	0.92	0.43	-	-	-
Period 3	-	6.69	5.65	1.74	1.62	0.58	-0.01	0.10	1.17	-	-
VALUES OF C											
Period 1	-	-346.4	-369.6	-323.6	-380.5	-	-	-	-	-	-
Period 2	-	-1624.2	-507.0	-15.2	-83.8	-567.2	-1841.8	-863.0	-	-	-
Period 3	-	-13400.3	-11329.6	-3493.4	-3238.0	-1166.7	16.4	-202.5	-2345.7		
VALUES OF t_0											
Period 1	-	1986.9	1995.6	2001.4	2015.8	-	-	-	-	-	-
Period 2	-	1993.8	1990.9	1867.3	2013.5	2008.9	2005.9	2012.1	-	-	-
Period 3	-	0.0	2004.4	2002.4	2002.8	2000.5	2073.4	2027.8	2012.2	-	-
R2											
Period 1	-	0.76	0.98	0.89	0.99	-	-	-	-	-	-

Period 2	-	0.79	0.74	0.01	0.30	0.77	0.85	0.44		-	-
Period 3	-	0.84	0.52	0.93	0.95	0.76	0.01	0.66	0.90	-	-
Std. Err. of q Coefficient											
Period 1	-	0.07	0.02	0.04	0.02	-	-	-	-	-	-
Period 2	-	0.42	0.11	0.05	0.05	0.11	0.27	0.34	-	-	-
Period 3	-	2.05	3.16	0.28	0.21	0.19	0.05	0.04	0.38	-	-
Std. Err. Of constant											
Period 1	-	136.75	41.14	78.79	31.48	-	-	-	-	-	-
Period 2	-	837.77	213.24	109.05	90.45	217.02	539.59	680.11	-	-	-
Period 3	-	4115.91	6337.04	554.94	425.39	381.25	96.50	83.03	765.87	-	-
t-statistic											
Period 1	-	2.54	8.98	4.09	11.96	-	-	-	-	-	-
Period 2	-	1.95	2.39	0.15	0.92	2.60	3.41	1.26	-	-	-
Period 3	-	-	1.79	6.31	7.63	3.07	-0.16	2.41	3.06	-	-

The results of the regressions for all efficiency levels are summarized in Table 1 (above). This table lists all of the regression parameters and regression statistics used in fitting the data to the cumulative market share model described above. For example, in the case of star efficiency level 2.0, the slope of the market share (represented by the value of *q*) in time period 1 is less than in periods 2 and 3. This indicates that the market share for appliances that have a 2.0 star rating or greater grows slowest in time period 1, then increases in period 2, and then increases down significantly in period 3.

Once that the values of *q* have been determined for each time period and each efficiency level, the logistic transformation is used to model the anticipated cumulative market share of each efficiency level. This model assumes that each new MEPS implementation (occurring in both 1999 and 2005) triggers the *q* value to change.

Cumulative Market Share Projections

This model produces 'S-curves', illustrating the changing cumulative market share value over time of each efficiency level. The S-curves are used to model three different historical scenarios. A description of the three scenarios follows:

- **Scenario 1**: No MEPS were implemented in either 1999 or 2005. This scenario models the cumulative market share if no MEPS had been implemented. This scenario is a counterfactual of the 1999 and 2005 MEPS. (The *q* value remains constant for each year in this scenario)
- **Scenario 2**: MEPS were implemented in 1999, but not in 2005. This scenario models the effect that the MEPS in 1999 had on the cumulative market share and estimates what the cumulative market shares would have been after 1999 assuming that no additional MEPS were implemented. This scenario is the second counterfactual.In this case, the *q* value for each year is the same period 2 and period 3, but different in period 1.
- **Scenario 3**: MEPS were implemented in both 1999 and 2005. This scenario models the effect that the MEPS had on the cumulative market shares. This scenario models the historical progression of cumulative market shares and closely resembles the actual data points. (In this case the *q* value is different in each time period for each year.)

As mentioned above, a change in MEPS policy such as the ones introduced in 1999 and 2005 are expected to trigger the value of *q* to change. A summary of the scenarios and the values of *q* that are used is summarized in the table below.

Table 2: Summary of Model Scenarios

Scenario	Description	Value of *q* parameter	Nbr. of Values of *q*
1	No MEPS	Constant *q*	1

2	MEPS in 1999	Value of *q* changes in 1999	2
3	MEPS in 1999 and 2005	Value of *q* changes in 1999 and 2005	3

Energy Efficiency Improvement

The goal of the cumulative market share projection is to evaluate the energy efficiency improvement and energy savings resulting from the 1999 and 2005 MEPS, as well as the rescaling of the labels in 2000 (which is effectively bundled into the 1999 MEPS change). The evaluation is based on the difference between the counterfactual scenarios (1 & 2) and the scenario that closely reflects actual historical changes (Scenario 3).

The energy efficiency improvement calculation is based on the comparative energy consumption (CEC), which corresponds to the energy that appears on the energy label. This energy consumption is measured in kWh/year and is used with the market share data to obtain a weighted average of the yearly energy consumption by energy star rating. The two steps in this calculation are: 1) Calculating the CEC for each star level for each year; 2) calculating the weighted average of the projected CEC by using the market share projections for each efficiency level for each star level. The equations below detail the calculation involved in the two steps mentioned above.

Comparative Energy Consumption

The refrigerator star rating algorithm[8] is:

$$SRI = 1 + \left[\frac{\ln \dfrac{CEC}{BEC}}{\ln(1 - ERF)} \right]$$

The terms from the equation above are defined as follows:

SRI is Star Rating Index (star efficiency level)
CEC is Comparative Energy Consumption (energy that appears on the energy label)
BEC is Base Energy Consumption (this is the line that represents the energy for a star rating of 1.0).
ERF is the Energy Reduction Factor (this is the energy reduction for each additional star).

The sales data analyzed provided the star rating. The sales by star rating, the CEC for each model, the average size and energy by star rating can also be calculated.

Weighted CEC

The *CEC* (label for annual energy) is weighted by the annual sales by model to obtain the yearly weighted average energy consumption for each star rating. The *CEC* for each efficiency level was then used in conjunction with the projected market share model to produce a projected counterfactual of consumed energy for each scenario.

Energy Savings

The energy savings are determined by calculating the difference between the weighted average energy consumption and the extrapolated weighted average energy consumption from the S-curves for both the 1999 MEPS and the 2005 MEPS. The difference is calculated as follows:

$$\begin{aligned} &Yearly\ Energy\ Savings\ from\ Scenario\ 2\ (1999\ MEPS) \\ &\qquad = (Projected\ Weighted\ Averave\ CEC\ from\ Scenario\ 2) \\ &\qquad - (Projected\ Weighted\ Averave\ CEC\ from\ Scenario\ 1) \end{aligned}$$

[8]Appliance Energy Consumption in Australia: Equations for Appliance Star Ratings.

$$
\begin{aligned}
Yearly\ Energy\ Savings\ from\ Scenario\ 3\ (1999\ and\ 2005\ MEPS) \\
= (Projected\ Weighted\ Averave\ CEC\ from\ Scenario\ 3) \\
-\ (Projected\ Weighted\ Averave\ CEC\ from\ Scenario\ 1)
\end{aligned}
$$

Where the weighted average CEC is derived from the sales data and the projected weighted average CEC is derived from the S-curves.

Results

Market Share Projections

Cumulative Market Shares

Figure 4 illustrates the cumulative market share in Scenarios 2 and 3. The dotted line in the figures represents the counterfactual scenarios, the solid lines represent the model fit of the scenarios, and the points are the actual market share data points.

In Scenario 2 the counterfactual is considered to be the cumulative market share of the efficiency levels assuming that no MEPS had been implemented in 1999 or 2005 (Scenario 1); in Scenario 3 the counterfactual is considered to be the cumulative market share of efficiency levels assuming that MEPS had been implemented in 1999 but not in 2005 (Scenario 2).

The model produced the cumulative market share projections for 1993 through 2010 for all the efficiency levels in Scenario 1. Scenario 1, in which there was no MEPS in 1999 or 2005, illustrates that in 1993 the only efficiency levels that have a cumulative market share greater than 0 are the lower levels, such as the 1.5, 2.0, 2.5, and 3.0 star levels. Higher efficiency levels did not constitute any percentage of the market in 1993, and the model determines that they only entered the market after the first MEPS in 1999. The model indicates that efficiency star levels 3.5 through 6 would not been introduced to the Australian market if it were not for the MEPS in 1999.

The lower efficiency star levels, levels 1.5, 2.0, 2.5, and 3.0, are also determined by the model to reach or approach their saturation point by 2009. For example, the star levels of 2.0 or greater constitute close to 100% of the market in 2009.

Figure 4 illustrates the market impact for both Scenarios 2 and 3. As shown in time period 2 of the plot for Scenario 2 (left-hand panel), the projected cumulative market share for star efficiency levels 1.5 – 3.0 is greater than the counterfactual cumulative market share, implying that for these low efficiency star levels the MEPS resulted in an increase of cumulative market share.Higher-efficiency levels, such as star efficiency levels 3.5 and greater, have no counterfactual because they did not exist in 1993, the start year for the data and on which was based the model. Therefore, the impact of the MEPS introduced in 1999 was to increase the cumulative market share of mid-range efficiency levels (i.e. 2.5 and 3.0 stars) and phase in higher efficiency appliances (i.e. 3.5 stars – 6.0 stars). The right-hand panel of Figure 4 illustrates Scenario 3, in which the MEPS was implemented in both 1999 and 2005 (this reflects reality). The projected cumulative market share of lower efficiency levels in time period 3 increase above the counterfactual and reaches the market saturation point. This increase is the case for star efficiency levels 1.5 - 3.5, where the solid line can clearly be seen rising above the dotted counterfactual. While the cumulative market shares of levels 1.5 – 4.0 increases above the counterfactual, the market saturation point is only reached by star efficiency levels 1.5 – 3.5. The increase in cumulative market share is most likely the result of increasing market shares in the recently introduced higher efficiency star levels, such as 4.0 – 6.0. However, the MEPS in 1999 seem to have caused SRI efficiency level 4.0 to jump, but it is then surpassed by the counterfactual. Levels greater than 5.0 have a cumulative market share of zero because those levels do not yet exist.

The increase in cumulative market share of star levels 1.5 – 3.5 most likely results from the increase in level 4.0 and 5.0. As a result of this increase in cumulative market share for low-efficiency appliances, the market makes room for higher efficiency appliances. As expected, the 2005 MEPS results in the introduction of higher efficiency appliances to the Australian market.

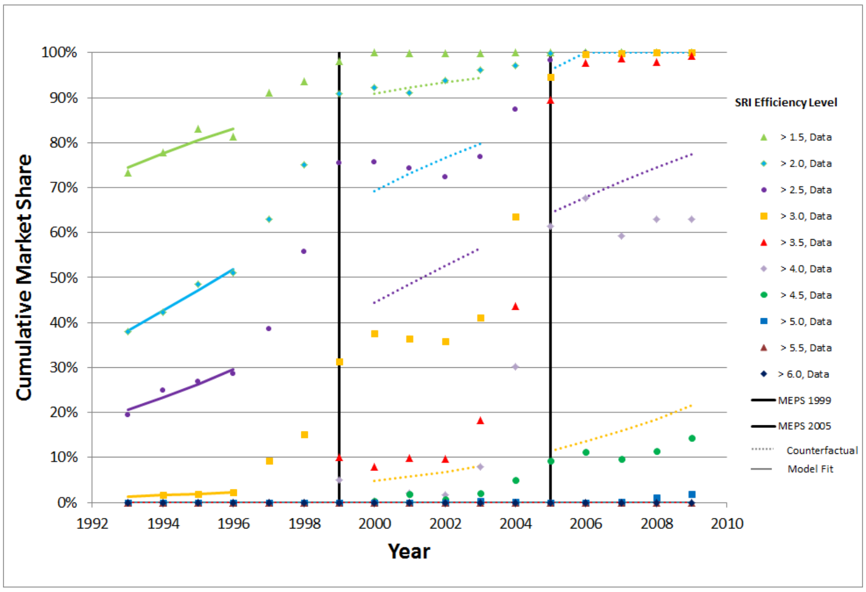

Figure 3: Adoption Curves of Australian Refrigerators-Freezers for Scenario 1

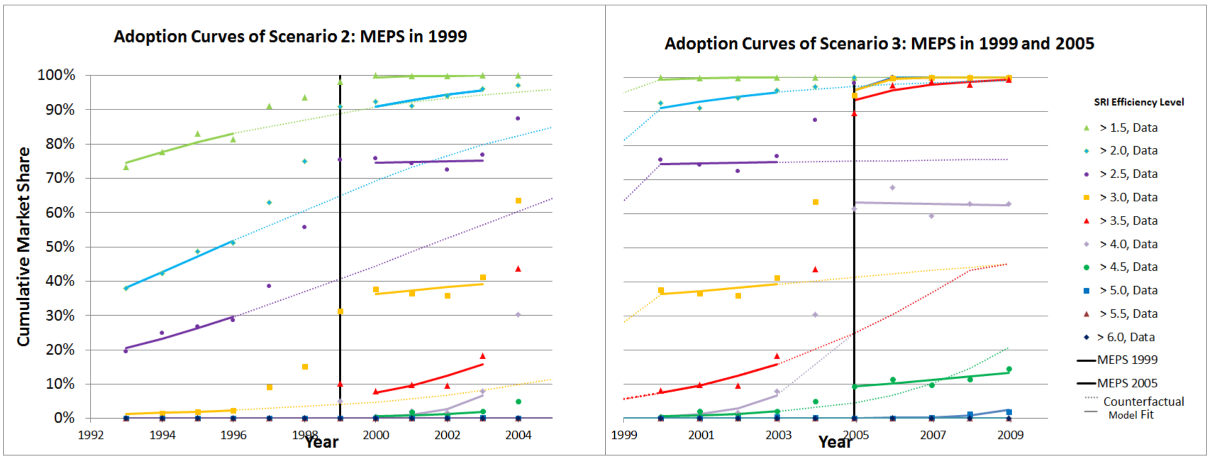

Figure 4: Adoption Curves of Australian Refrigerators for Scenarios 2 and 3

Energy Efficiency Improvement and Energy Savings

The left-hand panel of Figure 5 below illustrates the weighted average of energy consumption based on the market share data, as well as the weighted average calculated from the counterfactuals determined by the model. The right-hand panel illustrates the cumulative annual energy savings. It is important to note that the calculations of the cumulative annual energy savings for Scenario 2 include the impact of the label re-grade in 2000.

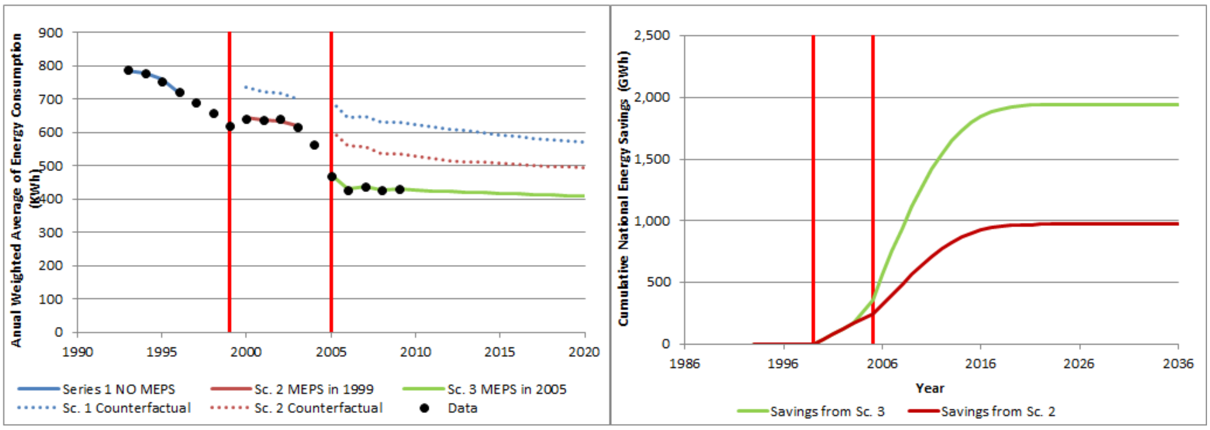

Figure 5: Annual Weighted Average of Energy Consumption (KWh/yr) and Cumulative Annual Energy Savings (GWh)

The black points represent the yearly weighted averages of energy consumption, calculated from data points provided by the market analysis, while the solid line is the weighted average of energy determined from the modeled S-curves. The dotted lines are counterfactuals extrapolated from the S-curves: the dotted blue line represents the counterfactual of Scenario 1 (no MEPS in 1999 or 2005) and the dotted red line represents the counterfactual of the MEPS introduced in both 1999 (Scenario 2). The solid green line represents the model fit for Scenario 3, which lines up nicely with the data points.

The energy savings from Scenarios 2 and 3 can be evaluated by looking at the area between both the dotted blue line and the solid red line, and between the solid green line and the dotted red line respectively.

As demonstrated by the right-hand panel of Figure 5 above, the MEPS in 1999 produces significant energy savings, however the savings are not as significant as when combined with the MEPS in 2005.While the 1999 MEPS served to phase in high-efficiency appliances and phase out low-efficiency appliances, it appears that the 2005 MEPS served to significantly accelerate the market and further increase energy savings.

Conclusion

The approach set out in this paper provides an innovative methodology for more objective evaluation of energy savings from different program measures implemented at different points in time. The starting point of the analysis was to apply a consistent diffusion curve to each efficiency category within each policy in order to measure a critical parameter that characterizes the effectiveness of the program. In particular, the construction of a policy "counterfactual" using this method represents an improvement over more aggregate methods. There are two reasons for this. First, separate modeling of each efficiency category using standard diffusion curves captures saturation effects more accurately than extrapolation of market averages. Second, the statistical methods outlined here allow for quantification of the model's reliability through estimation of the uncertainty on fit parameters[9].

The case of the Australian refrigerator efficiency program demonstrates both the advantages of this method, and its limitations. First of all, the interplay between the two types of programs that co-exist in the Australian program produces a complex picture. As can be seen in the figures above, MEPS cannot be seen as having simply accelerated the rate of improvement of efficiency in the Australian market. While MEPS were successful in raising the average efficiency of the market, once implemented they seem to have led to a period of relative stagnation in which the market shows little improvement until the announcement of the next round of MEPS. This is hardly surprising, as implementation of stringent MEPS will reduce opportunities for additional energy saving design

[9]The statistical analysis allows for quantification of uncertainties using error propagation, which will be considered in future studies.

improvements by manufacturers for some time after MEPS, especially where all models have to be fully re-engineered just to meet the new mandatory requirements.

Interestingly, a dynamic that can clearly be seen is that both MEPS implemented in during the period of study seemed to have induced the introduction of new higher-efficiency products into the market. It should be noted, however, that this effect is more prominent in the case of the 1999 MEPS, and may be conflated with the effects of the 2000 rescaling of the label categories, which for practical reasons have been folded into the savings estimates for Scenario 2 (MEPS 1999).

Despite the analytical rigor offered by this methodology, therefore, some understanding of the context of program implementation and the practical timetable of market reactions needs to be taken into consideration. For example, in the face of large energy reductions from new MEPS regulations, manufacturers have to start introducing new compliant models well ahead of the final implementation date. So some judgment is still required regarding the effective points where the policy measure started to have an impact. However, with further investigations and experience, it should be possible to provide common sense guidelines to allow the approach to be applied in a coherent manner in appropriate circumstances in a range of countries and for a range of different appliance types.

In conclusion, from this example, we judge that the analysis we applied provides a useful framework for policy analysis, but should be used with care. The two most important lessons from the Australian refrigerator case:

- MEPS Announcements dates (in contrast with MEPS implementation dates) have an important early effect on transformation of the market;
- The time coincidence of the 1999 MEPS and the rescaling of the labels makes the separate impacts of these two policy shifts difficult to disentangle.

The method set out in this paper can already be shown to have provided some insights into these questions. Breaking up the market into labeling categories clearly shows three effects that drive market transformation (1) elimination of low-efficiency units as a response to MEPS (2) gradual increase in market share of high-efficiency products as a result of labels and (3) manufacturer response to announcement of MEPS. While these effects were known by researchers and practitioners of efficiency programs, the methodology described here provides a robust and consistent way to describe these effects and, ultimately, design more effective programs.

A related point is that where a product may be subject to a large number of program changes at relatively short intervals over a long period, it is unlikely that there will be sufficient time to establish reliable values for the diffusion parameters required for this type of analysis. The other observation is that to apply this methodology, some form of categorical system of energy labeling needs to be in place. Ideally this should be visible to purchasers and should provide a relatively neutral and objective assessment of the relative efficiency of different product types.

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YAECI – Yearly Appliance Energy Costs Indication

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Abstract

The main objective of the YAECI [1] project is to provide customers with information at the point of sale on the yearly running cost of products with an energy label, in order to stimulate the uptake of affordable efficient products.

The EU energy label currently provides the consumer with information on the energy efficiency (energy class), energy consumption and several other energy-related aspects. However, the energy label lacks the information on an aspect that many consumers find very important i.e. the product´s (yearly) running costs. As is well known, a product that is initially somewhat more expensive can in fact work out to be cheaper in the long run due to the running costs being less expensive.

The calculation for the running costs of the YAECI project is based on the following data for each participating country:

1. (average) cost per kWh based on the national electricity prices
2. data on the product´s electricity consumption as included on the energy label.
3. Optionally – water costs, based on data on the label and national average water price.

Retailers, which are participating to the YAECI project, are publishing the data on the products yearly running costs, the “Energy Indicator”, at the points of sale to inform their customers so they can choose energy efficient products.

The project is organised by partners in 11 EU countries and has started with the preparatory phase in March 2012 and aims to attract retailers to display the running costs. The YAECI project was initiated as a follow-up to the successful programme “Energie Weter”, organised in the Netherlands in hundreds of shops. In individual countries different product groups are covered, white appliances covered by the new energy label and displaying the annual energy consumption being dominant.

Products covered by the YAECI project

For the selection of products, the YAECI project team considered [2] all appliances which are covered by the Directive on energy labelling. The Directive 92/75/EEC and the corresponding implementing Directives cover the following products (hereafter “old label products”):

- Refrigerators, freezers and their combinations;
- Washing machines, dryers and their combinations;
- Dishwashers;
- Ovens;
- Electrical lamps;
- Tumble dryers;
- Air-conditioning appliances.

The Directive 2010/30/EU which amends the Directive 92/75/EEC was adopted in May 2010. On the date of writing, Delegated Regulations were adopted for the following products (hereafter “new label products”):

- Refrigerators, freezers, their combinations and wine storage appliances;
- Washing machines, dryers and their combinations;
- Dishwashers;
- Televisions;

- Tumble Dryers;
- Electrical lamps and luminaires;
- Air-conditioning appliances.

Overall, the number of old label products sold in shops is decreasing and thus becoming less significant for their coverage by future YAECI action. For this reason only the new label products are covered by the YAECI energy indicator. Nevertheless, a methodology which associates the old and new energy labels has been developed for assisting the retailers, in case they prefer to display the energy indicators in all of their products.

The combined washer dryer is the only exception in which an old label product is included since no new energy label has yet been developed for this product category. Ovens and light bulbs and tubes, which are covered by the EU Directives on energy labels, are not included in the selection for the reasons provided below.

Products which are not covered by the EU Directive on energy labelling are not covered by the YAECI project because this would impose difficulties in establishing commonly accepted methodology and in collecting the necessary data from the manufacturers. This difficulty was experienced in the Dutch initiative EnergieWeter which attempted to include a wider range of products (e.g. laptops and computer monitors).

Some aspects related to specific product categories which were considered during the selection process are explained below.

Refrigerators, freezers and their combination, washing machines and dishwashers

The potential impact of displaying an energy indicator on wine refrigerators, which are covered by the new Directive on energy labelling, is expected to be insignificant in all countries due to their relatively low sales (both in terms of units and power capacity). For this reason, wine refrigerators have been excluded from the scope of products covered in this project.

Tumble dryers and combined washer dryers

Tumble dryers and combined washer dryers have been excluded from the YAECI selection in countries with warmer climates. In addition, according to available market data, in some New Member States (including CZ, RO and SI), the market penetration of this type of products is generally much lower compared to the western European countries (e.g. FR and NL). However, the market trends show that the market penetration is increasing rapidly and therefore their inclusion was considered in CZ, CR, RO and SI as well.

The new Delegated Regulation on tumble dryers was published recently and it will become mandatory for all tumble dryers, which are placed on the market after May 2013. For this reason, only new label tumble dryers are included the database which will be developed by the project team to provide data on running costs to the retailers. Nevertheless, a methodology which associates the new and old label for tumble dryers has been developed as well to assist the retailers until no more old label products will be sold.

Ovens

The use of electric ovens is generally higher compared to gas ovens but their share of overall household electricity consumption, is relatively low. In the EU, the market penetration of electric ovens will continue to rise but this will not have any significant impact on the electricity consumption, since the current share of electric ovens is already very high.

Nevertheless, ovens have been excluded for the scope of product covered in this study due to the likelihood of similar difficulties that were experienced in the EnergieWeter initiative. The main difficulties relate to the estimation of the usage patterns which seem to differ considerably not only between different countries but also between households within the same country.

Air-conditioners

The use of air-conditioners in the residential sector is increasing in all EU countries, regardless of the local weather conditions. However, in the short-term the impact of this product will remain rather insignificant in countries with cold climates, because the main driver of the air-conditioners market is the cooling demand (regardless of the fact that some air-conditioners can be used for heating as well).

The new and old energy labels for air-conditioners cannot be correlated because they are based on different classifications and standards. For this reason, no methodology has been developed for old label air-conditioners.

Electrical lamps and luminaires

Usually, the retailers who trade white goods and televisions also sell light bulbs. Nevertheless, this product category has considerably different characteristics compared to other products covered by the EU legislation on energy labelling, limiting the impact of their potential inclusion. Most significantly, due to the small size of light bulbs and their packaging, the energy indicator might not be noticed by the consumers.

Product selection

Table 1 shows the selection of products which is mainly based on the market penetration and trends of different products in each country. Due to their large market penetration, the refrigerators and freezers, the washing machines, the dishwashers and the televisions are covered by all countries. The inclusion of washer dryers, tumble dryers and air-conditioners is excluded in some countries due to their low market uptake. For the reasons explained in the previous section, ovens and light bulbs have been excluded from the scope of analysis performed in this study.

The table also shows which labels are taken into account in the development of the YAECI database of running costs. The combined washer dryers is the only old label product which is included in the database since the new label for this product has not been published yet.

Table: Final YAECI product selection

Product	A	CZ	CR	DE	ES	FR*	MT	NL	PT	RO	SI	Old	New
Refrigerators and freezers **	√	√	√	√	√	√	√	√	√	√	√		√
Washing machines	√	√	√	√	√	√	√	√	√	√	√		√
Dishwashers	√	√	√	√	√	√	√	√	√	√	√		√
Televisions	√	√	√	√	√	√	√	√	√	√	√		√
Combined washer dryers		√	√			√		√				√	√***
Tumble dryers	√	√	√	√		√		√			√		√
Air-conditioners			√		√	√	√		√	√	√		√

* For the present YAECI is not be implemented in France

** Including built-in freezers and excluding wine – refrigerators

*** Not published yet

Calculation of the Energy Indicator

The term "energy indicator" refers to the running cost which will be displayed in shops either within the price tag of the products or separately. The aim of the energy indicator is to provide to the consumers an estimate of the running cost of products. This information is not included in the EU energy labels. The information which is currently displayed in the EU energy labels can assist the consumers to estimate their potential energy savings from more efficient products but not in monetary terms. This poses a risk that the information which is provided in the EU energy label (i.e. energy class and energy consumption) may not encourage consumers to purchase the most performing products.

For the development of YAECI energy indicator, the project team assessed different options covering the following 4 aspects:

- definition of the time frame of the indicator;
- selection of a common or a diverse approach between the participating countries;
- definition of potential presentation standards for energy indicator;
- adding supplementary information.

The selection of the approach for each of these aspects is described below.

The time frame of the indicator

The running cost of products can be calculated on an annual basis or for longer periods (e.g. 5 or 10 years). The project team assessed the option of displaying the running cost of products over their lifetime. In this option, the average lifetime for each product category would be based on a common source of information. Potential sources considered, include the base cases from the Ecodesign preparatory studies which were carried out in the context of the Ecodesign Directive . These base cases serve as a reliable source since they have been developed in consultation with the manufacturers. However, this option was abandoned due to the possibly significant differences between the actual lifetimes of products and the possible opposition by retailers and manufacturers on using one average value for all products.

For this reason, the project team selected the option of displaying the annual running cost which will be mandatory for all participating retailers and all products. This approach has already been applied in a real situation (under the EnergieWeter initiative in the Netherlands) which gives it additional credibility. Nevertheless, the retailers will be encouraged to display the running cost for longer periods without associating those periods with the lifetime of the respective products. The annual cost savings might appear insignificant and therefore the provision of the running costs for a longer period will further encourage the consumers to purchase energy efficient products.

Context and appearance

The context of the energy indicator will be based on EnergieWeter approach. Similar to the Dutch initiative, the YAECI energy indicator will follow the following principles:

- the energy indicator will be presented in the form of the statement "Energy cost per year is € X" (written in national languages and currency);
- in shops, the energy indicator must be set on the price tag (preferable on the last line) and for online sales the indicator will be presented in the product specification;
- the use of the YAECI logo is encouraged but not mandatory;
- the YAECI logo can be displayed on the price tags of the products and on separate tags.

This approach is preferred because of its acceptance by the retailers and also as its effectiveness has already been tested and applied in real life situations under the EnergieWeter initiative.

Use of supplementary information

The project team examined the possibility of including additional aspects of the running cost which could be used as supplementary information of the energy indicator. For this reason, the significance of the share of water consumption to the total running cost was analysed. The inclusion of water consumption was considered as it is one of the key elements included in the EU energy label and is largely related with the environmental impact of products. The products that would be affected by the inclusion of water consumption are the washing machines, dishwashers and washer dryers.

Next Table shows an estimate of costs that was carried out by the project team, for Austria, Malta and Portugal.

Table: Weight of water consumption in washing machines and dishwashers

Countries	Share of water cost in the annual total running cost		Comments
	Washing machines	Dishwashers	
Austria	40- 50%	n.a.	Water cost = € 3.00 per m^3
Malta	40 - 54 %	11 - 20 %	Water cost = € 3.04 per m^3 based on a national avg. consumption of 55 m^3 per person/year
Portugal	28 - 42%	7- 13 %	Water cost = € 1.28 per m^3 based on a national avg. consumption of 120 m^3/year

Depending on the specific models used for the estimation of the weight of water ranges between 28%-54% for washing machines and 7%-20% for dishwashers. The washing machines models used in the calculations for Malta and Portugal were the same but not for Austria where different models were applied.

Concerning washer-dryers, according to an estimate based on the performance of 4 units sold in France, the share of water cost ranges between 21%-39%. The share of water consumption is significant in this product category because most washer-dryers have a condensation-based drying function which uses cold water to cool down the drying process. In fact, the lower value (21%) of the range above, referrers to an air-vented appliance whereas the share of water consumption in the other three models which use water in the drying process, ranges between 33%-39%.

At least for the washing machines and washer dryers (especially the water-cooled units) the cost of water represents a significant share of total cost. Although the weight of water consumption is not as significant in dishwashers, it would still be reasonable to include the cost of water, to ensure consistency on the overall approach.

Overall, the benefits of including the cost of water consumption are the following:

- water represents a significant share of the total running cost for some products (e.g. in washing machines the share ranges 28%-54%;
- the water cost is included in other similar initiatives (e.g. in France);
- the water consumption is included in the EU energy label.

Following are the main disadvantages of including water consumption:

- potential difficulties might arise in defining a representative average cost for the water consumption (e.g. differences between municipalities/ regions and at different levels of consumption);
- the inclusion of water might cause difficulties for the evaluation of the YAECI action since this will be largely based on the share of products per energy class.

Therefore, although the water consumption represents a significant share in the total running cost of certain product categories, it also poses several challenges which relate mainly to the definition of a representative average water price. For this reason, the running cost of water consumption is not mandatory in the YAECI action but it will be supported by YAECI if this is requested by the retailers.

Approach on the energy indicator

Based on the analysis of different options for the definition of the energy indicator the mandatory principles that should be followed by all retailers are the following:

- the annual running cost must be displayed in all shops and products;
- the annual running cost will be presented in the form of the statement “Energy cost per year is € X”.

Non-mandatory, but desirable principles are the following:

- the energy running cost for a different number of years (e.g. 5 and/or 10 years) may also be displayed as supplementary information;
- retailers may display the YAECI logo in the tags which will include the energy indicator.
- Another optional element is the following:
- retailers may include the running cost for water consumption calculated based on the methodology provided by YAECI.

Methodology for the calculation of the running costs

This chapter describes the methodology for the calculation of the annual running costs for products selected in YAECI project. For all product groups which are displayed with the old and new EU energy label, two different formulas have been developed (expect for air-conditioners).

The development of the YAECI database takes into account only the methodologies referring to the new energy label (except for combined washer dryers for which only the old energy label exists). The methodologies for these products will be embedded in the YAECI database. All other methodologies have been developed to assist the retailers to make their own estimates, in case they wish to also display the running costs of products using the old energy label.

Refrigerators, freezers and combined units (displayed with the new energy label)

Both the new and the old energy labels indicate the annual energy consumption. In both labels the energy consumption is calculated based on similar standards . The formula for the calculation of the annual running cost is the following:

ARC= AEc x EP

Where:

ARC= Annual running cost

AEc= Annual energy consumption per kWh according to the label

EP= Electricity price per KWh

Washing machines (displayed with the new energy label)

The new energy label shows the weighted annual energy consumption which is calculated at 220 cycles per year and takes into account the energy consumption of the following programmes:

- standard 60 °C cotton programme at full load (Et,60);
- standard 60 °C cotton programme at partial load (Et,60½);
- standard 40 °C cotton programme at partial load (Et,40½).

The weighted annual consumption of washing machines also takes into consideration the weighted powers in “off- mode” (P0) and in “left-on mode” (Pl).

The formula for the calculation of the annual running cost of washing machines is the following:

AEC= AEc x EP (this cost figure will be displayed by the participating retailers)
AWC= AWc x WP (this cost figure might as an extra option be displayed by the participating retailers)
ARC= AEC+ AWC
Where:
ARC= Annual running cost
AEC= Annual energy cost
AWC= Annual water cost
AEc= Annual energy consumption per kWh according to the label
EP= Electricity price per KWh
AWc = Annual Water consumption (L)
WP= Water price per L

Dishwashers (displayed with the new energy label)

The annual energy consumption of dishwashers is provided in the new energy label. This is calculated based on 280 standard cleaning cycles using cold water fill and the low power modes.

As in the case of washing machines the new energy label for dishwashers also takes into consideration P0 and Pl. The formula for the calculation of the annual running cost of dishwashers is similar to the one for washing machines mentioned above.

Televisions

All televisions which were placed on the market after March 2012 should be displayed with the new energy label. Currently there are still some unlabeled televisions on the market but this number is gradually decreasing.

The energy label for the televisions indicates the annual energy consumption and therefore the formula for the calculation of the annual running cost is straightforward:

ARC= AEc x EP
Where:
ARC= Annual running cost
AEc= Annual energy consumption per kWh according to the label
EP= Electricity price per KWh

Combined washer dryers

At the time of preparation of this report, the combined washer dryers were covered only by the old energy label. In relation to the energy consumption, the energy label includes the following information:

- energy consumption per complete operating cycle (washing, spinning and drying) using standard 60 °C cotton cycle with a full capacity wash load and a “dry cotton” drying cycle;
- energy consumption per washing cycle (washing and spinning only) using standard 60 °C cotton cycle.

The energy label also shows the capacity (in kg of cotton) for both the washing and drying functions. The following main aspects in the operation which needs to be taken into account for the calculation:

- consumers do not always use the drying function;
- the drying capacity does not often match the washing capacity and is normally smaller;

For this reason, the calculation of annual energy consumption of washer dryers is relatively more complex compared to other product groups. Consumers might use the drying function more than once for a single load of washing. Alternatively, consumers might prefer to wash loads which match the (normally smaller) drying capacity. There is no information on these specific usage patterns. Based on several assumptions derived from the energy label methodology, ecodesign and Energieweter the following assumptions have been applied:

- on average the consumers use the washing machine 220 times per year and the tumble dryers 160 times per year.
- for washing machines the average load is estimated at 3.4 kg for those with a capacity of 5.4 kg
- the total number of the wash-only cycles is 58 (200 kg, 3,4 kg in each cycle).
- the 40 °C programme is the most commonly used (63%) followed by the 60 °C one (37%).
- the energy consumption of the 40 °C programmes correspond to the 72% of the energy consumption of the 60 °C programme.
- the actual energy consumption compared to the energy consumption which is included in the label is 87 %.

The formula of the estimation of the annual energy consumption of washer dryers is as follows:

AEC= [(160 x 5.4/Cd x Ew,d) + (58 x 5.4/Cw x (Ew x 37% +Ew x 72% x 63%) x 87%)] * EP
(this cost figure will be displayed by the participating retailers)

AWC= [(160 x Wt) +(58 x Ww)] x WP
(this cost figure might as an extra option be displayed by the participating retailers)

ARC= AEC+AWC

Where:

ARC= Annual running cost

AEC= Annual energy cost

AWC= Annual water cost

Cd= Capacity in the drying function according to the energy label in kg

Cw= Capacity in the washing function according to the energy label in kg

Ew,d= Energy consumption per cycle in the washing/ drying function in kWh

Ew= Energy consumption in the washing only function in kWh

EP= Electricity price per KWh

Wt = Total water consumption per cycle in L according to the energy label

Ww= Water consumption per cycle in L in washing and spinning functions according to the product fiche

WP= Water price per L

Tumble Dryers (displayed with the new energy label)

The new energy label on tumble dryers is mandatory for all products placed on the market from May 2013. The new energy label indicates the weighted annual energy consumption which is estimated at 160 cycles per year by taking into account the energy consumption of the standard cotton programme at full and partial loads (Edry and Edry½). In addition to the air-vented and condenser tumble dryers, the new energy label also covers gas-fired appliances which are out of the scope of the YAECI project.

The formula for the calculation of the annual running costs of the air-vented and condenser tumble dryers which are be displayed with the new energy label is the following:

ARC= AEc x EP
Where:
ARC= Annual running cost
AEc= Annual energy consumption per kWh according to the label
EP= Electricity price per KWh

Air-conditioners (displayed with the new energy label)

The old label cannot be associated with the new energy label which becomes mandatory in January 2013. For this reason only products displayed with the new energy label will be taken into account.

The new Delegated Regulation on air-conditioners covers the following types:

- Single and multi split;
- Single duct;
- Double duct.

There are three main types of single and multi split air-conditioners according to which the information provided in the energy label varies. Particularly the specific types and the information provided is as following:

- Reversible air-conditioners – annual energy consumption in kWh per year for cooling and heating. For the heating function, 3 different - geographical zone oriented - values are given.
- Heating-only air-conditioners - annual energy consumption for 3 different geographical zones.
- Cooling-only air-conditioners – annual energy consumption.

Similarly for the single and double duct air-conditioners, depending on the specific type, the information on energy consumption might refer to heating-only, cooling-only or to both heating and cooling functions. A key difference of the single and double duct air-conditioners compared to the single and multi splits is that the hourly energy consumption is indicated. In addition, for the heating function a single value is given instead of 3 zonal values.

The formula for the estimation of the annual energy running cost for split and multi split air-conditioners is the following:

ARC= (AEc,h,x + AEc,c) x EP
Where:
ARC= Annual running cost
AEc,h,x = Annual energy consumption in the heating function per kWh according to the label, in the respective heating season
AEc,c= Annual energy consumption in the cooling function per kWh according to the label
EP= Electricity price per KWh

For the single and double duct air-conditioners the formula is as follows:

ARC=[(HEc,h x HUh) +(HEc,c x HUc)] x EP
Where:
ARC= Annual running cost
HEc,h = Hourly energy consumption in the heating function according to the label
HEc,c = Hourly energy consumption in the cooling function according to the label
HUh = Annual hours of use in the heating function, defined by partners
HUc = Annual hours of use in the cooling function , defined by partners
EP= Electricity price per KWh

Definition of data per country

The calculation of the running cost is based on data which is mostly provided by the EU energy label, but certain parameters are defined by the project team. Specifically, the following data needs to be defined:

- energy prices per country;
- water prices per country (optional);
- usage patterns of single and double-duct air-conditioners (applicable in CR, ES, FR, MT, PT, RO and SI).

The data for each of these categories and their sources are described in the sections below.

Energy prices per country

Table 4 shows the household energy prices in all countries represented in YAECI. These prices come from Eurostat and they refer to the first semester of 2012 and will be updated at the beginning of the YAECI action. These prices include all taxes and they are charged in direct current (DC) bands for annual consumptions between 2,500 and 5,000 kWh;

Table: Energy prices per country (average of the first semester of 2012)

Country	Energy price €/KWh
AT	0.1975
CR	0.1208 (0.9109 kn)
CZ	0.1497 (3.7700 CZK)
DE	0.2595
ES	0.1822
FR	0.1412
MT	0.1700
NL	0.1858
PT	0.1993
RO	0.1050 (0.4612 lei)
SI	0.1542

The project team also examined the possibility of obtaining data from national sources (e.g. statistical offices, energy agencies) and for this purpose information was collected as well from such sources. Although national authorities and statistical offices often provide more up-to-date data, Eurostat was selected as the most appropriate source, due to the differences that exist between countries in the definition of characteristics which relate to the electricity prices (e.g. corresponding bands and inclusion of taxes). In this context, the use of data from Eurostat can ensure consistency throughout the whole duration of YAECI.

Water prices

The inclusion of the cost of water consumption as a supplementary information to the energy indicator is optional. The inclusion will be based on the height of water prices at the national, regional or local levels and on the preferences of the participating retailers. Table 5 shows the average water prices per m3 in 7 countries covered by YAECI. These prices are either provided by national statistical sources (CZ and FR) or they have been estimated based on average prices from various suppliers. In addition, these estimates entail the following three aspects:

- the prices correspond to an annual consumption of approximately 120 m3/year;
- they reflect costs of both water supply and sewage;
- any extreme cases (i.e. particularly high or low prices in certain regions) have been excluded.

Table: Water price per m3

Country	Water price €/m^3	Source
CR	1.52 (11.33 kn)	Estimate
CZ	2.92 (73.44 CZK)	CZSO
FR	1.73	INSEE
MT	3.20	Estimate
PT	1.28	Estimate
RO	1.29 (5.86 lei)	Estimate
SI	0.66	Estimate

Involving retailers and endorsement

Retailers are the key actors in this action. They have to provide the information on the yearly energy costs at the point of sale and in advertisements. They benefit from clearly demonstrating their environmental commitment and by attracting consumers to more efficient products that may be (somewhat) more expensive but can generally also provide a higher margin.

The participation of retailers is an essential part of the action. Each project participant (in 10 countries) is expected to ensure in writing the participation of at least 1 national retailer chain with at least 7 participating retailers and 8 individual retailers or 2 national retailers with at least 7 participating retailers or at least 15 individual retailers.

The list of retailers actually cooperating with the YAECI programme at the moment of writing this paper is already beyond expectation. Besiddes the 1400 reatler partriciapting in EnergieWeter in the Netherlands several hunderds of shops in the other participating YAECI countries have committed themselves to the project. Amongst them big retailer chains and web shops which will be visible at the YAECI website www.appliance-energy-costs.eu . The actual date of the launch of the visibility in the shops for the consuklers of the YAECI Energy Indicator will differ from country to country and will take place in the 2nd quarter of 2013.

Retailers are understood to benefit by joining the scheme, since they will have an extra selling tool to attract the attention of the consumer and have stronger arguments to sell (sometimes) more expensive products.

A priori, manufacturers/suppliers would provide the energy and water consumption figures of their appliances to the YAECI database. The YAECI consortium developed this European database which extends the Dutch “Energy Indicator” database containing already 4600 products of 40 brands from the start. During the project it had been decided to subcontract a service provider the consortium helping with the data gathering.

The Dutch version of the Energy Indicator was created in 2010 in cooperation between the Ministry of Environment, several appliance suppliers/importers and the association of contracting installing companies and technical retailers in the Netherlands (UNETO-VNI). The YAECI consortium members foster a similar cooperation and support in the participating countries beyond the Netherlands. [3]

Evaluating results

Evaluating the impact of the project activities is one of the keys to understand if projects such as YEACI have the potential to further improve the position of energy efficient appliances on the market. A specific project activity provides both an evaluation of the market effect of the action and how the action was received by retailers and consumers. The evaluation of the action has 3 components:

- a quantitative evaluation at the end of the action answering the question whether the market share of more efficient appliances has increased for retailers that participated in the action,
- a qualitative evaluation of the action regarding consumers,
- a qualitative evaluation of the action regarding retailers.

The qualitative evaluations regarding consumers and retailers are foreseen half way the action. In this way the results of the qualitative evaluations can be used to guide and, if necessary, further improve the approach of the action in between (mid term evaluation) whereas the quantitative evaluation aims at assessing the maximum result possible.

Description of the tasks

Preparation of the evaluation

The preparation already starts at the beginning of the project; defining the type of information required to be collected from individual retailers. The following table illustrates the information to be collected from participating retailers.

Table: Information to be collected from individual retailers

Please enter below the overall sales data per product group within the time period indicated above						
	Overall Sales		If you do not wish to give the exact number of sales please indicate the range of sales numbers by crossing below the suitable section			
Productgroup	Number of sold appliances [pieces]		0-100 pieces	>100-250 pieces	>250-500 pieces	>500-750 pieces
Refrigerators						
Freezers						
Fridge-freezers						
Washing machines						
Dishwashers 60cm						
Dishwashers 45 cm						
Televisions						
Combined washer dryers						
Tumble dryers						
Air-conditioners						

Qualitative evaluation consumers

Based on a questionnaire template, the evaluation regarding consumers is done by interviews directly at the Point of Sale (target group: consumers that bought some appliance for which yearly energy cost data was displayed). By few initial questions, the customers are asked if they agree participating in the interview. The more detailed interview will be done directly at the PoS or soon afterwards by a telephone interview. In each country at least 15 personal interviews with consumers are done. Per country a short evaluation report is produced being part of the overall evaluation report. This report is sent to representatives from national consumer organisations (if available) in order to ask for their opinion and discuss their further support for the action.

Qualitative evaluation retailers

In this task the evaluation of the action regarding retailers is carried out in each country. Each participating chain or retailer is interviewed based on a questionnaire template. The evaluation will include information about the promotional activities taken from their side, and the feedback and possible challenges during the sales conversation on the side of consumers regarding their purchasing decisions. Per country a short evaluation report is produced being part of the overall evaluation report.

Quantitative effect of the action

Before the start of the action, participating retailers in each country have to be instructed which kind of market data have to be prepared and collected (market share of more efficient products (to be defined as the products to be in the one or two most efficient energy classes) compared to less efficient products).

Data is acquired at the beginning of the action (before the actual providing of information on the yearly energy costs started), after 18 months and after 32 months of the action. If publicly available, this data is compared to a base line of data from the total national market (desk research). Per country a short evaluation report is expected to be produced being part of the overall evaluation report.

Evaluation report

By disclosing annual running costs on appliances at the point of sale, a new methodological approach of consumer information and motivation to buy efficient appliances will be tested and evaluated in a representative selection of EU countries.

Promoting the project activities

Promoting the yearly appliance costs to consumers is one of the key conditions of the success of the programme. Within the programme, each national partner is expected to organize a range of activities, most of them in direct cooperation with the participating retailers. Examples of the promotion activities include:

- Project website, with national language sections for 11 participating countries
- Brochures for shop assistants and consumers
- Leaflets and/or posters for consumers
- Press conference (including press release) and seminars
- Articles in general media

Activities already undertaken within the project are regularly published on the project website:

http://www.appliance-energy-costs.eu/eu/news/

References

[1] YAECI project website: www.appliance-energy-costs.eu

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The YAECI Project has been supported by the Intelligent Energy Europe programme. The sole responsibility for the content of this website lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the EACI nor the European Commission are responsible for any use that may be made of the information contained therein.

Supported by INTELLIGENT ENERGY EUROPE

Study on the Energy Efficiency of Flat Panel Televisions in China: Implications for Energy Efficiency Standard, China Energy Labeling Program, and National Incentive Policies

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Abstract

Flat panel televisions (TVs) have replaced traditional cathode ray tube (CRT) models as the dominant type of TV in China and are widely used for residential and similar purposes. TV energy efficiency has risen quickly over the last several years due to the rapid development of technology and the incentives from national subsidy programs. As a result, the current Chinese energy efficiency standard (EES) for flat panel TVs (GB 24850-2010) became outdated, and a revision process was initiated in 2011. A revised draft of the standard was released for public comments in August 2012.

This paper is based on the study of "Market Analysis of China Energy Efficient Products, MACEEP". The study assesses the energy efficiency of flat panel TVs that are available on the Chinese market. Based on the market data collected, the paper examines China's test method for TV energy performance, compares the energy efficiency requirements in current EES with the new revision draft, and tracks the evolution of TV energy efficiency over time. Additionally, it assesses the effectiveness of the EES and appliance subsidy programs for this product. It concludes with recommendations for developing more informed test methods and improved energy efficiency requirements for the EES, as well as adding more useful information to the TV energy label.

1. Introduction to TV market and policies in China

1.1. Market transformation from traditional cathode ray tube (CRT) TVs to flat panel TV

Historically, as elsewhere, the Chinese television market was dominated by cathode ray tube (CRT) televisions (TVs). However, beginning around the year 2005 [1], there has been a swift and complete market shift to flat panel TVs.

There are currently two basic types of flat panel technologies that dominate the TV market: plasma display panels (PDPs) and liquid crystal displays (LCDs). LCD TVs break down further into two sub-types, differentiated by the backlighting source. These are cold cathode fluorescent lamps (CCFLs) or light emitting diodes (LEDs). Currently, the LCD TV market is undergoing a transition from CCFL to LED backlighting.[1]

There are clearly a number of technological differences between PDP and LCD televisions. This study compares these models based on their energy performance.

1.2. Energy efficiency requirement, labeling program, and test method for flat panel TVs in China

1.2.1 Energy efficiency requirement and labeling program

China's energy efficiency standard (EES) GB 24850-2010, *Minimum allowable values of energy efficiency and energy efficiency grades for flat panel televisions*, was introduced in December 2010. It defined the minimum energy performance requirement (MEPR) that all flat panel televisions must meet, outlined the energy efficiency tiers (EETs) denoting different levels of energy efficiency, and described the energy efficiency test methodology [2]. Table 1 shows the energy efficiency index (EEI) threshold values for the EETs.

Due to the rapid development of TV technology and major policy intervention (see Sections 1.3 and 2.5), the energy efficiency of televisions on the Chinese market has improved rapidly since the issuance of the EES. As a result, the Chinese Government initiated a revision process in 2011 to upgrade the TV EES in accordance with new technologies available on the market. A revised draft standard was released for public comments in August 2012. Table 1 details the EET and MEPR requirements proposed in the new draft.

Table 1: Energy efficiency requirements in the current (2010) EES [2], and revised (August 2012) draft [3]

	Energy Efficiency Index (EEI) Tier Thresholds Requirements*					
	Current (2010) EES			Revised draft EES (August 2012)		
TV type	Tier 1	Tier 2	Tier 3**	Tier 1	Tier 2	Tier 3**
LCD	1.4	1.0	0.6	2.6	2.2	1.7
PDP	1.2	1.0	0.6	2.2	1.8	1.4
PDP (normalized to LCD equivalent) ***	0.35	0.29	0.17	0.70	0.58	0.45

* The method for deriving EEI changed between 2010 and 2012 (See Section 1.2.2).

**Tier 3 corresponds to the MEPR, which is the least efficient level, and Tier 1 is the most efficient level.

*** The EEI thresholds defined in both the two versions of EES for LCD and PDP televisions are not directly comparable (See to Section 1.2.2). The PDP (normalized to LCD equivalent) shows EEIs for PDP televisions if calculated on an equivalent basis to LCD televisions.

In March 2011, three months after the original EES was implemented, the Chinese government announced an energy labeling scheme for televisions. The television label (Figure 1) shows the specific energy efficiency tier of a television model, in these two cases Tier 2. Absolute values for the

[1] There is no information to suggest PDP TVs are experiencing any technological change similar to the transition being experienced in LCD TVs.

EEI and standby power are also stated at the bottom of the label. The label also includes the manufacturer's name and product model number.

Figure 1 China Energy Label for Flat Panel TVs (LCDs to the left and PDPs to the right)

As shown in Figure 1, EEI is used as the main indicator of energy efficiency on the TV energy label. However, as EEI is a technical term, it is assumed that typical consumers are highly unlikely to understand its significance. Moreover, the information is misleading as the EEIs for LCD and PDP are not directly comparable with each other (See Section 1.2.2). Specifically, there is no information on power. Thus, the information on the label gives the consumer no indication that a PDP television is actually consuming more energy than an equivalent LCD model, especially LED type.

Therefore, it is recommended adding a power consumption value to the label, either in addition to or instead of the EEI value. Furthermore, if possible, the label should display a typical daily, weekly, or annual energy consumption, which is likely to be of significant value to the consumer. Such revisions would more accurately reflect the real difference in power demand between products and thus be more useful for consumers' decision making.

1.2.2 Test method and energy efficiency calculation in the current and revised EES

Televisions are globally traded products; as such, the test method used to measure their energy efficiency performance has been aligned in much of the world through full or partial adoption of the International Electrotechnical Commission (IEC) standard 62087. However, China's TV test method differs significantly from that of the IEC.

The current Chinese television test method was first introduced in December 2010 as part of the original EES for televisions [2]. The test method requires televisions to be set to a standard viewing condition by adjusting "brightness" and "contrast" based on an eight-level grey pattern (See Figure 2), and the adjustment is undertaken in a dark room. This pattern is a brightness signal, with two rows grey levels against a background of 50% grey level. The first row consists of four levels: 0% (absolutely black), 5%, 10%, and 15%. The second contains 85%, 90%, 95%, and 100% (absolutely white). At first, brightness is adjusted to the point where the two neighbouring levels of 0% and 5% grey in the first row can be just differentiated by the test personnel. Then contrast is adjusted from

100% to a lower status, such that the 95% and 100% levels in the second row can be just differentiated by the test personnel. Test personnel then repeat the adjustment procedure until both neighbouring groups (0%-5% and 95%-100%) could be exactly differentiated at the same time. At that point, the brightness and contrast levels are deemed to have been set and are used for the rest of the testing procedures.

The test method also states “if such condition cannot be achieved, adjust the image to the best quality possible and record the brightness and contrast levels.” However, there is no definition of “best quality.”

Figure 2: Eight-level grey pattern used in Chinese TV energy efficiency test method GB 24580-2010

Once the adjustment is complete, the luminance of the screen is calculated based on the average of nine values measured at points spaced across the screen (P_0 to P_8 – see Figure 3) in a pattern dependent upon the screen size and shape.

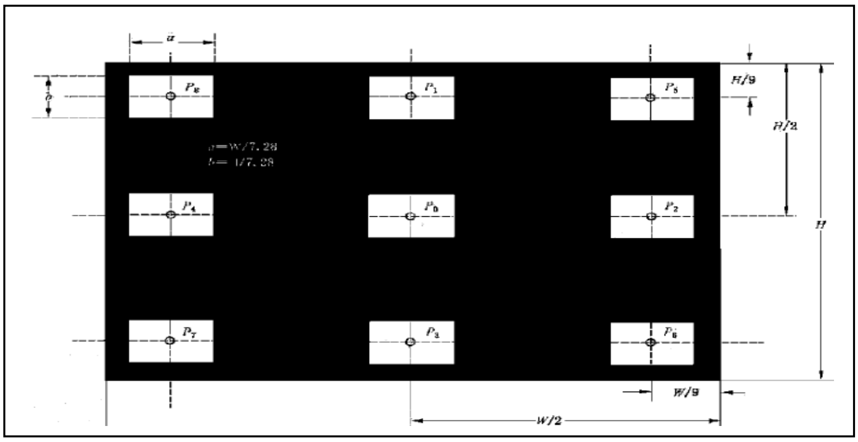

Figure 3: Nine-point layer used in China’s TV energy efficiency test method GB 24580-2010

The IEC standard broadcast loop is then played, and the power consumed by the television is measured during the broadcast. The energy efficiency of the television is calculated as the average measured luminance multiplied by screen size and divided by total power consumed, as shown below:

Equation 1

EEI = [Luminance * Screen Size / (Power-10W)]/ EEI_{ref}

Where,

EEI is the Energy Efficiency Index of TV; and
Luminance is the averaged luminance of the nine points as mentioned above; and
Screen Size is the viewable size of TV screen; and
Power is the tested on-mode power; and
10W is the power regarded for signal processing;[2] *and*
EEI_{ref} equals 1.1 and 0.32[3] *for LCD and PDP respectively.* [2]

There are three issues with the GB test method that should be considered in the current revision process:

1. The brightness and contrast of the television under the GB test method are adjusted in a dark room. This does not reflect a typical real-life viewing environment where most people would watch the television with a certain amount of background light in the room [4]. Consequently, levels of brightness and contrast required in the test are likely to be insufficient to enable satisfactory viewing in a normal environment.

2. For LCDs, the eight-level grey pattern required by the test method may be achieved through adjustment of either the television's screen brightness (by changing the angle of crystals of the panel) or the backlight brightness (by changing the light output of backlighting sources) settings. However, the two methods will typically result in considerable difference in power consumption and hence efficiencies.

3. Test personnel are required to make an accurate but ultimately subjective differentiation between neighboring grey-levels in the pattern. Differences in perception between numerous personnel may result in considerable variation or even errors to the testing results.

To address these issues, Chinese policy makers may wish to consider harmonizing the Chinese test standard with IEC 62087. It would not only resolve the issues with the current Chinese test standard noted above, but could also contribute to improved international trade. However, changing national test standard may need many efforts from a variety of stakeholders and could take a long time. Therefore, in order to solve the problems mentioned above in a timely manner, consideration should be given to a revision of the current Chinese test method to:

1. Reflect more realistic viewing situations, e.g. by requiring the adjustment of "brightness" and "contrast" in the presence of a defined "typical" level of background light. However, this may require further research.

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[2] If a television has an Analog RF interface, it must be the system used in the test. Due to the TV signal system, almost all TVs sold in the Chinese market have this interface, therefore, the analysis in this report uses "10W".

[3] There are two EEI_{ref} values for PDP's in the EES depending on the screen resolution. For PDPs with intrinsic resolution of 1920*1080 and higher, 0.32 is applied and for the others 0.45 is applied. In this report, the PDP EEI_{ref} of 0.32 is used because the proportion of LCD products with resolution of 1920*1080 is similar to that of PDPs, and overall the market trend is increasingly towards high resolution televisions.

2. Differentiate the adjustment of television “screen brightness” from “backlight brightness” to ensure that no manufacturers take advantage of this potential loophole and products are tested fairly.

3. Avoid, or at least minimize, subjective measures in the test procedure, e.g. develop some equipment to replace test personnel to read the eight-level grey pattern.

The test method in the revised draft television standard has changed slightly from the original EES. As shown in

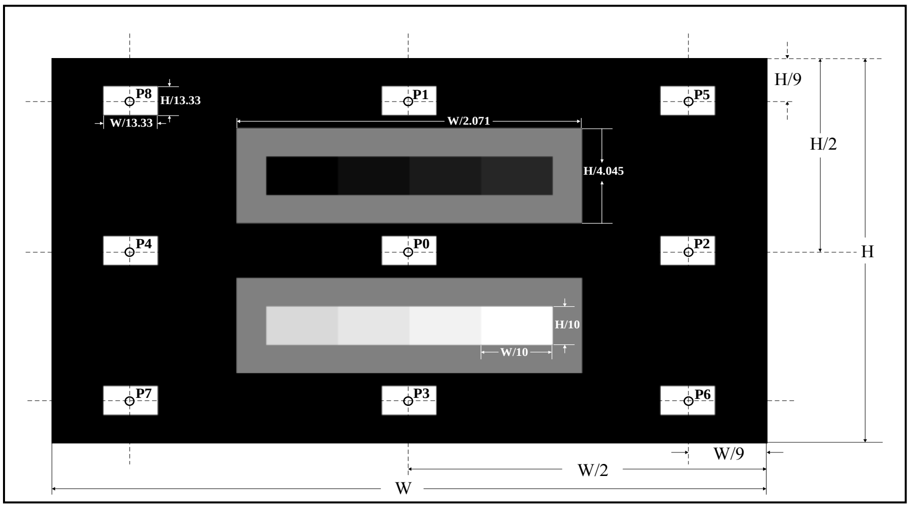

Figure 4: New test pattern proposed in revision draft of GB 24850

, a new pattern for testing has been proposed, which integrates the two patterns.

Figure 4: New test pattern proposed in revision draft of GB 24850

However, according to the testing principles, this minor change will not cause any difference in the test result.

The influential change actually lies in the calculation method. The newly proposed equation for EEI calculation in the revision draft is as below:

Equation 2

EEI = (Luminance * Screen Size / Power)/ EEI_{ref} ……………………..…

Where every term means the same as Equation 1

EEI = [Luminance * Screen Size / (Power-10W)]/ EEI_{ref} except EEI_{ref}, which is re-defined as below:

EEI_{ref} equals 1.0 and 0.32[3] for LCD and PDP respectively.

Comparing with Equation 1, the value of EEI_{ref} for LCD has changed from 1.1 to 1.0. Additionally, the 10W of power regarded for signal processing has disappeared in the new equation. These two changes in the equation have significantly impacted the stringency level of energy efficiency requirements, especially for small size TVs (see Section 2.4).

1.3. The Appliance Subsidy Program

The Chinese government announced a subsidy program in May 2012, entitled "Subsidize energy efficient products, Benefit people." The program covers a variety of categories of energy-using products and provides financial subsidies for energy efficient models. Flat panel TV is one of the beneficiary products. The program has caused a major transformation towards energy efficient of televisions in the Chinese market and has also played a key role in accelerating the revision of the television EES (see Section 2.5). Table 2 shows the levels of financial support for televisions of varying efficiency and screen size under the 2012 subsidy program in Chinese Yuan (RMB).

Table 2: Levels of support under the 2012 subsidy program for TVs of varying efficiency and screen size [4] [5]

Screen Size (inches)	LCD (RMB/unit)		PDP (RMB/unit)	
	EEI>=1.7	EEI>=1.9	EEI>=1.4	EEI>=1.7
19-32 (not including)	100	150	-	-
32-42 (not including)	250	300	250	250
42 and above	350	400	350	350

2. Market Analysis

Market research could show how products on the market perform against relative policies, in this paper's case, EES, Energy Labeling Program and subsidy program. Market data discloses products' energy efficiency status and how it evolves over time. Through comparison between market data and policy requirements, conclusions could be made on the effectiveness of such policies. Moreover, recommendations are then provided for potential improvement of the policies.

2.1. Data sources and types

Data used for analysis in the study of Market Analysis of China Energy Efficient Products (MACEEP), which this paper is based on, are primarily from internet sources, including online shops, the China National Bureau of Statistics (NBS), and other public sources. The data was collected for market study as of July 5, 2012. Any new models that entered the market afterwards were not included. Data types include product model number, specific product type, energy efficiency, energy efficiency tier, size, power, date of market entry, and price. All analysis in this report is model-based.

Online data should sufficiently represent the general TV market of China for two reasons. Firstly, online shops in China offer a larger number of models than any single retail store. They also offer

[4] EEI values were calculated using 2010 energy efficiency standard methodology.

delivery services, so even consumers in remote cities and towns have access to all of their products. Secondly, large appliance chain stores in China such as GOME and SUNING, as well as some of the major appliance manufacturers, all have online shops.

2.2. Market distribution by product type

As shown in Figure 5, the Chinese TV market is dominated by LCD TVs, with LED and CCFL TVs splitting the entire market share by 66% and 28% respectively. PDP televisions only represent 6% of the models available on the market.

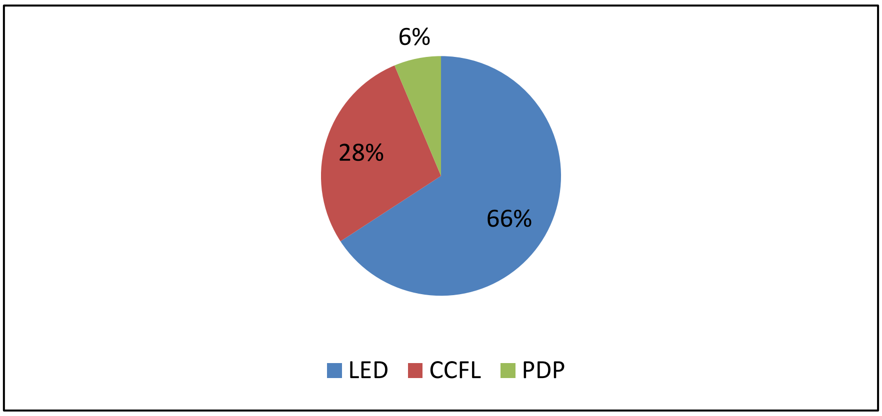

Figure 5: Distribution of different types of TVs

2.3. Distribution of EEI

Figure 6 shows the distribution of televisions available on the Chinese market by EEI as declared by manufacturers. Again, note that EEI values for LCD and PDP televisions cannot be directly compared (See Section 1.2.2). It is clear that the products with the highest efficiency levels are LED backlight TVs. Further, despite the majority of EEI declarations being below 2.0, the highest EEI could reach up to 3.5. This may imply that there is significant room for policymakers to increase performance requirements in the future.

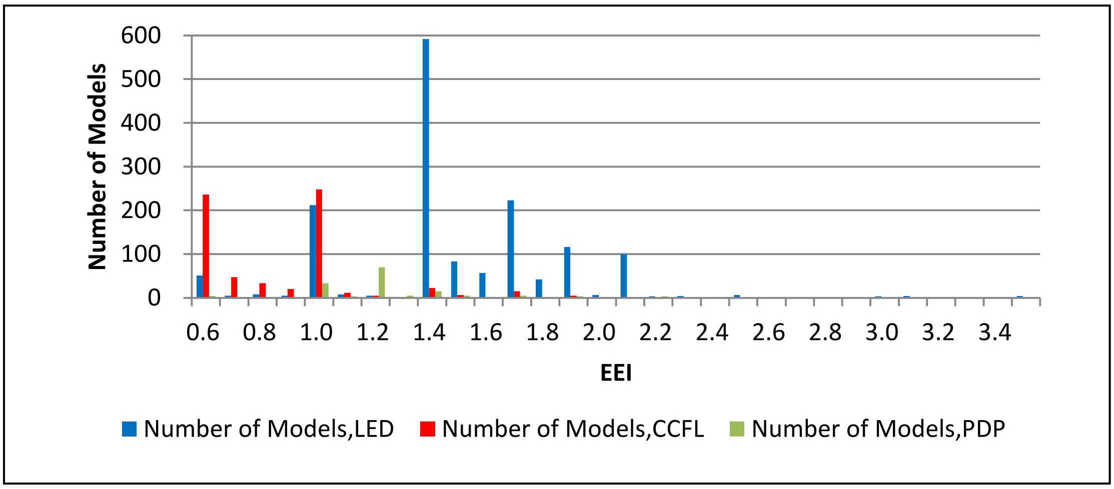

Figure 6: Distribution of EEI

Figure 6: Distribution of EEIComparing the declared product EEIs with the EET threshold requirements in GB 24850-2010 (Table 1) and the subsidy program criteria (Table 2) shows that the

declared EEIs of many models are barely satisfying the minimum requirements. This implies that, to some extent, TV manufacturers may be taking advantage of the fact that there is no regulation for declaration tolerance. Manufacturers could simply declare the energy efficiency of their products at the values that would benefit them the most, rather than test values.

Therefore, it is recommended that policymakers should develop a regulation that requires manufacturers to declare their products with the actual test value. This will assist in future policymaking as more accurate information will be able to assess and help consumers to know the real energy performance of their options.

2.4. Comparison of EEI requirements in the current EES and the revised draft

Section Test method and energy efficiency calculationdescribes the change in calculation method of EEI in the revision draft. This section will explore the impact of such change on enery efficiency and the TV market.

In an attempt to understand how current TV models rate on energy efficiency according to the levels of stringency proposed in the revised draft of EES, the proposed EEI (EEI_{new}) needs to be converted to the current EEI ($EEI_{current}$). This enables us to directly compare current TV models with the new EEI requirements. Equation 3 was developed by the author based on Equations 1 and 2 for this purpose.

Equation 3

$$EEI_{current} = (Power * EEI_{ref.new}) * EEI_{new} \; / \; [(Power - 10) \times EEI_{ref.current}]$$

According to Equation 3, $EEI_{current}$ and EEI_{new} was plotted against power for each tier on

Figure 7

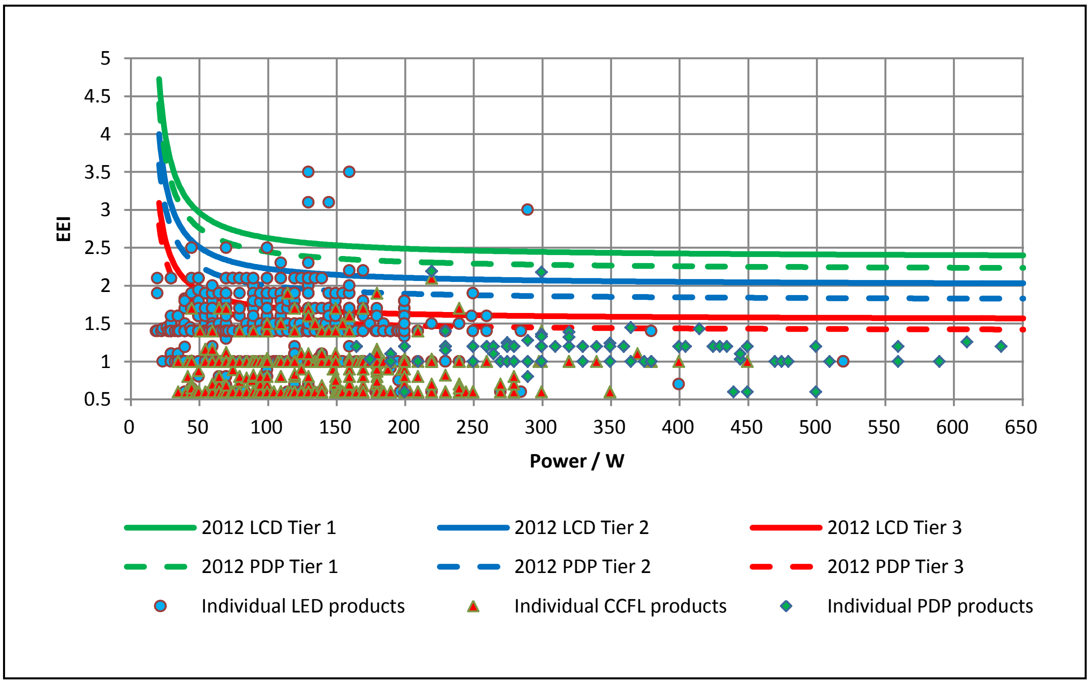

Figure 7: EEIs of models on the market against EES requirement of EEInew for both LCDs and PDPs. The declared EEI values of the models on the market are shown in the graph to compare with the EEI requirements[5].

Figure 7: EEIs of models on the market against EES requirement of EEInew for both LCDs and PDPs

Figure 7 shows a significant improvement in EEI_{new}. For both LCD and PDP models, the new MEPRs (Tier 3) are even higher than the current Tier 1 requirements, which are 1.4 and 1.2 respectively (See Table 1). However, EEI_{new} is much more stringent for low power TVs, which normally means small size TVs. This could be problematic because energy efficiency standards are supposed to be more stringent for large-sized products, as they are normally associated with higher energy consumption.

If the proposed requirements of EEI in the revised draft are fully adopted in the final version of the new EES, they will significantly impact the makeup of the TV market. As shown in

Figure 7**Error! Reference source not found.**, there are very few TV models with power lower than 100W that could meet the new MEPR. According to the data collected under MACEEP, those models are typically LEDs below 40’’ and CCFLs below 30’’. This implies that the majority of the TV models in this size range will be eliminated from the market. A rough estimate based on the Figure 7 is that, should the draft EEI_{new} be fully adopted, 50% of LED models, 80% of CCFL models, and 95% of PDP models will be eliminated from the market.

There are several policy implications associated with EEI_{new}. Firstly, it is too aggressively stringent for nearly all TVs, and may unexpectedly eliminate most of the models from the market. Secondly, EEI_{new} is much more stringent for small-sized TVs than large-sized ones.[6] However, from the standpoint of energy saving, the revised EES should contain more stringent requirements or cap values for products with large capacity because they normally consume more energy.

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[5] In **Error! Reference source not found.**, the requirement of EEI_{new} (curves) is based on values of test power as defined in the equations, while the scattered EEIs of models on the market are based on the declared powers by manufacturers. These two “powers” differ. For test power, some of the functions (e.g. automatic brightness control, internet connection, etc) are turned off and some settings are adjusted to the test mode. The declared power is supposed to be the highest possible power the product could consume during operation. However, they are very much linked and should be close in value. So, as the values of test power are not obtainable, the declared power is used as a substitute and it would provide close results for this analysis.

[6] EEI_{new} being less stringent for big size TVs is based on the comparison with $EEI_{current}$ and there might be argument that maybe $EEI_{current}$ is more stringent for big size TVs and EEI_{new} is trying to re-balance it. However, according to the data collected under MACEEP, on which this paper is based, it shows that average EEIs of relatively bigger size TVs are not any lower than small size TVs, which indicates that $EEI_{current}$ is not being more stringent for big size TVs. Therefore, it’s concluded that in nature EEI_{new} is less stringent for big size TVs.

Thus, it is recommended that policy makers should re-consider the requirements to avoid unexpected elimination of TV models from the market. Meanwhile, requirements should be comparably stricter for big size products, which normally are of higher absolute energy consumption.

2.5. Market Transformation

This section discusses TV market evolution over time and policy intervention impacts on television efficiency. Figure 8 shows the energy efficiency tier and the average EEI declared for televisions at the time of market entry. Although not of equal lengths, the time periods selected are considered critical periods and correspond to the following events:

1. The two months prior to compulsory labeling of televisions on March 1, 2011;
2. The ten months following the introduction of the energy label through the end of 2011;
3. The first period of 2012 prior to the announcement of subsidy threshold levels on May 20th, 2012; and
4. The period after the announcement of subsidy levels up to the point of data collection completion on July 5, 2012.

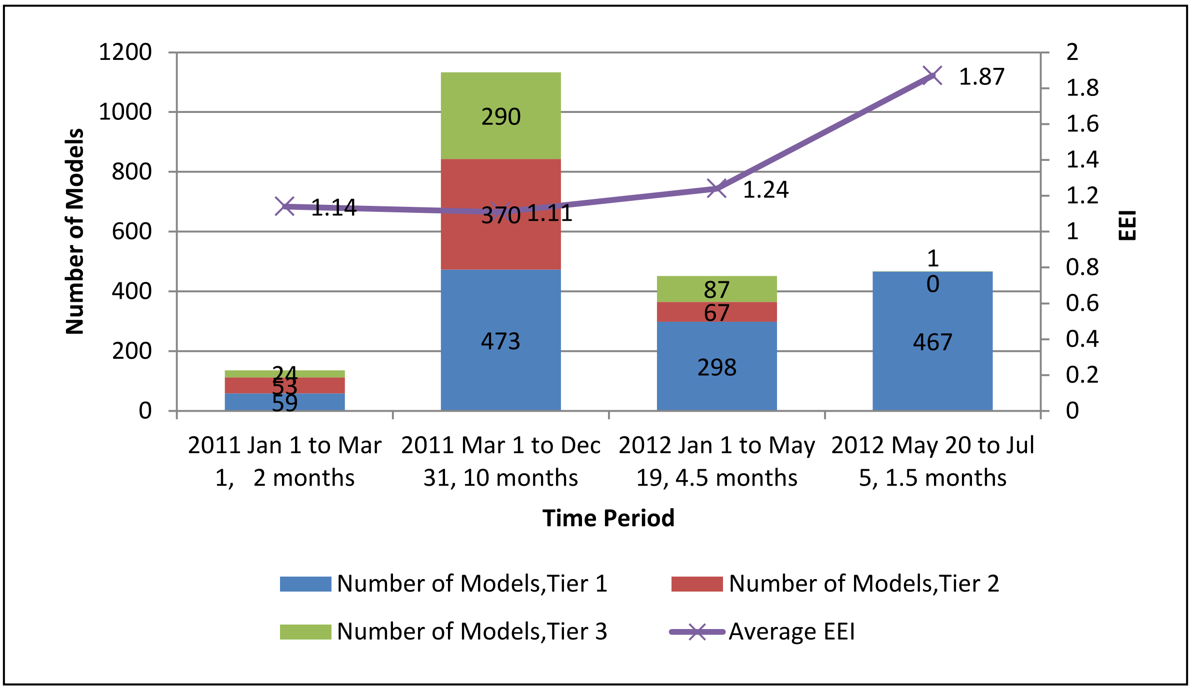

Figure 8: Trends in the energy efficiency tiers and average EEI declared for televisions at the time of market-entry[4]

As demonstrated above, the proportion of products declared in the Tier 1, Tier 2, and Tier 3 energy efficiency categories remained broadly stable over time. There was a slight migration to higher tier levels from Jan 1 to May 19 in 2012, resulting in the minor improvement in average EEI. However, the pattern and proportionate number of declarations changed sharply after the announcement of the subsidy program in May 2012. Over one and a half months, as many products were registered as over the full preceding 4.5 months. Almost all of these were Tier 1 products whose declared EEI values were equal to or exceed 1.7, which is the minimum requirement of the subsidy criteria. This indicates that the incentive programs are having a substantial impact on the market.

3. Conclusions and Recommendations

Based on the analysis above, the following policy implications and recommendations are derived for policies related to flat panel TVs in China**.**

3.1. Revised Energy Efficiency Standard

1. The proposed EEI_{new} in the revision draft is being aggressively stringent for nearly all sizes of TVs, which may unexpectedly eliminate most of them from the market. Also, it is much more stringent for small size TVs than big size ones.

   It is recommended that policy makers should re-consider the requirements so that they are not unexpectedly eliminating TV models from the market and the new requirements should be comparably stricter for big size products, which are normally of higher absolute energy consumption.

2. Test method of TV energy performance could be problematic. To address these issues, it is recommended that in the long term, GB test method harmonizes with IEC 62087. In the short term, policy makers may consider the following options:

   - Reflect realistic viewing situations, e.g. by requiring the adjustment of “brightness” and “contrast” in the presence of a defined “typical” level of background light.
   - Differentiate the adjustment of “screen brightness” from “backlight brightness” to ensure that no manufacturers able to take advantage of this potential loophole and products are tested fairly.
   - Develop some equipment to replace test personnel to read the eight-level grey pattern to avoid, or at least minimize, subjective measures in the test procedure.

3. The derivation of EEIs for PDPs and LCDs is based on a biased method in both the current EES and the revision draft. It makes the EEI value of PDPs appear to be close to LCDs. However, PDPs could consume much more energy than LCDs in real application, especially when compared with LED backlit type of TVs.

   It is recommended that policy makers should develop energy efficiency requirements for LCDs and PDPs on a technology neutral basis so that consumers could be able make purchase decisions based on comparison of true energy performance.

3.2. Revised Energy Labeling Program

4. EEI is used as the main indicator of energy performance on TV energy label. However, it is a technical term and could be hard for typical consumers to understand its significance. Moreover, the information could be misleading as the EEIs for LCDs and PDPs are not directly comparable with each other.

   It is recommended using power consumption value on the label. Furthermore, if possible, the label should display a typical daily, weekly, or annual energy consumption, which could valuable to consumers. Such revisions would more accurately reflect the real difference in power demand between products and thus be more useful for consumers' decision making.

5. It is observed that some manufacturers are declaring products right on the lower threshold of energy efficiency tier requirement. This shows that they may be taking advantage that there is no regulation for declaration tolerance.

   It is recommended that policy makers should develop a regulation that requires declaration of products with the test value. This will assist in future policymaking as more accurate information will be accessible and help consumers to compare real energy performance of their options.

References

[1] HC360.com, *Color TV Industry Status of China, 1st Quarter of 2007*.

[2] GB 24850-2010, *Minimum allowable values of energy efficiency and energy efficiency grades for flat panel televisions*.

[3] GB24850-xxxx, *Revision of GB 24850-2010, Version of "For Comments"*.

[4] CLASP 2011, *Analysis of Background Illuminance Levels during Television Viewing*.

[5] *Detailed rules for promoting energy efficient flat panel TVs under Programme of "Subsidize energy efficient products, Benefit people"* at: http://www.jienenghuimin.net/sFileShow1.jsp?index=446

TV Energy Consumption Trends and Energy-Efficiency Improvement in the Context of the Ecodesign Directive (EU) No 642/2009 for mandatory use of the TV Energy Label

Beate Diga

Results of the Continuous and Precise Evaluation of the Technical and Economic Potential for Saving Energy - based on GfK Retail and Technology Reporting

Abstract

Technology and smart environments are becoming an increasingly important factor in the everyday life. Thus the identification of potential energy improvements for technical consumer goods can change markets. The EU directive on TV establishes a framework of Eco design requirements.

> „(10) Ecodesign requirements should harmonise electricity consumption requirements for televisions throughout the Community, thus contributing to the functioning of the internal market and to the improvement of the environmental performance of these products." [1]

Since November 2011 energy labels for TVs are mandatory in the European Union. The objective of this analysis of the European TV market[2] with its economic and technical background is to provide information necessary to improve the efficiency of TVs with insights in complex and competitive markets and their impact on energy consumption.

1. Introduction and Methodology

The overall goal is to provide relevant information to support and accelerate potential TV efficiency improvements with regards to:

- TV market assessment for EU 25 countries with significant technological trends (market size, LED TV, OLED TV, 3D and Smart TV with its impact on energy consumption). The large-scale transition towards LED TV's reduces the impact of retributive trends like screen size and increasing TV sales on total TV energy consumption.

- distribution of the TV Energy Label in Europe; importance and evolution of the different classes

- usage related issues (TV viewing time, saturation of TVs in households, replacement cycles) market dynamics and their impact on the energy consumption related issue.

This paper discusses the energy consumption trends and energy efficiency labelling schemes that were introduced in 2011 in accordance with the new EU directive and implemented to the European television market. We will use the technical and economic background of the European television market as the basis for this analysis and will evaluate how changes in the energy efficiency labelling scheme in Europe will influence market trends and accelerate energy efficiency for televisions. The

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[1] COMMISSION REGULATION (EC) No 642/2009 of 22 July 2009, implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to Eco design requirements for televisions, p.1.

[2] Unless mentioned, all data related to TV mentioned hereafter are based on market sales out data audited within the retail panel by GfK Retail and Technology in 25 selected European countries, these are: Austria, Belgium, CZ, DK, Estonia, Finland, France, Germany, UK, Hungary, Ireland, Italy, Greece, Latvia, Lithuania, Netherland, Poland, Portugal, Slovakia, Slovenia, Sweden, Spain, Luxemburg, Bulgaria, Romania (Malta and Cyprus not audited)

sales data used in the analysis represents international data and is provided by GfK Retail and technology GmbH, Nürnberg.

Methodological annotation

Worldwide, GfK Retail and Technology enjoys the reputation among both manufacturers and retailers as being a specialist in monitoring technical durable goods markets, as well as offering a high degree of insight and experience. With our research we are discovering new insights into the way people live, think and shop.
We have our origins in the universities of Germany, continuously nurtured through our work with pioneering clients, academic institutions and management consultancies. And our thought leadership has been recognized across the world. Quality is the hallmark of everything we do. In the digital world, the availability of data has made its provenance and reliability crucial. Our high standards and scientific precision continue to set us apart.

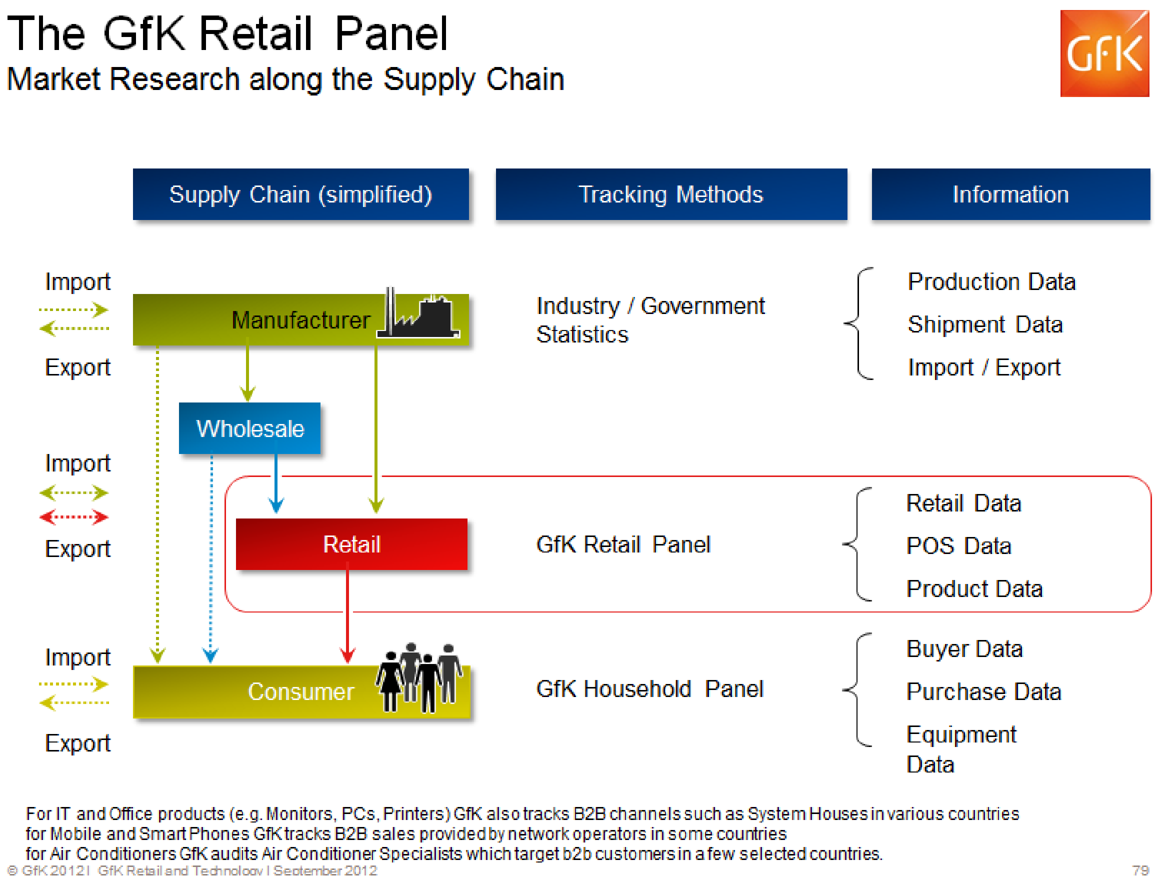

Figure 1: Source: GfK Retail and Technology

International GfK Retail Panel

The term “retail panel research” defines the use of a panel to collect concrete facts, using a homogeneous system. The electronic data is collected at regular intervals from a panel of retail outlets, which are selected, and if necessary modified, to represent the current structure of the universe of relevant channels of distribution.

The main static and dynamic objectives are to generate (static) quantitative sales data relating to a specific time period, and to reflect current (dynamic) market trends in terms of relevant market segments, product and price groups. It should identify both short and long-term changes in individual markets or market segments, so that management in both retailers and manufacturers are provided with an accurate information base. This can provide the basis for management to make decisions on an empirical basis with regard to the planning, control and monitoring of marketing strategies.

The data forming the basis of the retail trade panel should be complete with regard to the following three aspects, giving a solid and undistorted basis for:

- Complete recording of all relevant channels of distribution.
- Complete recording of the entire product range of the product groups in which there is an interest.
- Complete recording of the relevant product features of each individual product.

In this way the data relating to product features, product groups, sales and distribution structure can be clustered or analysed.

After the goods categories which are to be audited have been unambiguously defined in terms of their product characteristics, the relevant channels of distribution in which these goods categories are physically offered for sale are defined. A basic study works out the current total number of outlets (structure, number, regional distribution) in these channels. On the basis of this information a representative sample of outlets is recruited using the quota method, in which the data is to be collected in future by the field analysts or from electronic data-carriers (where there are stock control systems). The data collected in this manner is then checked, extrapolated and processed. It is then despatched to individual clients either in physical form through printed reports or electronically using special software:

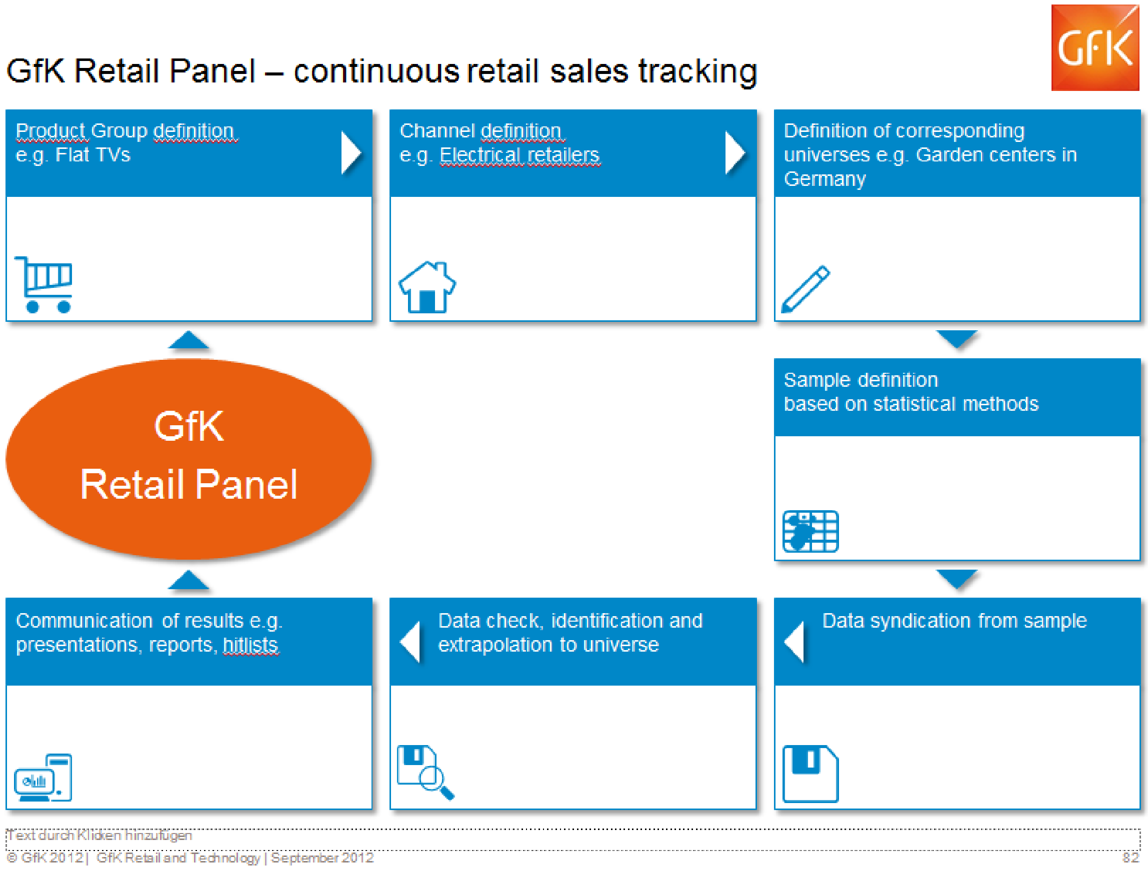

Figure 2: Source: GfK Retail and Technology

The international GfK Retail Panel provides such information to a very high standard of accuracy. Instead of assumptions and opinions, objective facts are provided in terms of sales, purchases, stocks, prices and distribution levels for every single article within defined channels of distribution. This level of detailed information forms is an important basis for decision-making.

All figures regarding sales volume or market share mentioned in this work are based on the international GfK Retail and Technology retail panel in **25 selected European countries, these are: Austria, Belgium, CZ, DK, Estonia, Finland, France, Germany, UK, Hungary, Ireland, Italy, Greece, Latvia, Lithuania, Netherland, Poland, Portugal, Slovakia, Slovenia, Sweden, Spain, Luxemburg, Bulgaria, Romania (Malta and Cyprus not audited)**. Data from this retail panel show retail sales out information including volume, value, price, feature sets etc. for defined product groups down to single item level. Statements regarding energy consumption in Watt are based on the mandatory Energy EU energy label. The calculation of energy consumption in kWh is based on an on-mode time of 4 hours per day plus 20 hours standby.

2. TV market assessment for EU 25 countries with significant technological trends in the context of the new European Energy label

TV sales are affected by many variables, such as economic development, technological trends or relevant policy instruments like the Energy label. In addition new lifestyle trends like Smart TV are redefining the role of the product with effects on viewing hours, standby power and total TV energy consumption. Global TV sales were 258,7 mio. units in 2012 and expected to reach 264,1 mio in 2013, showing an impressive growth of 18% since 2008.

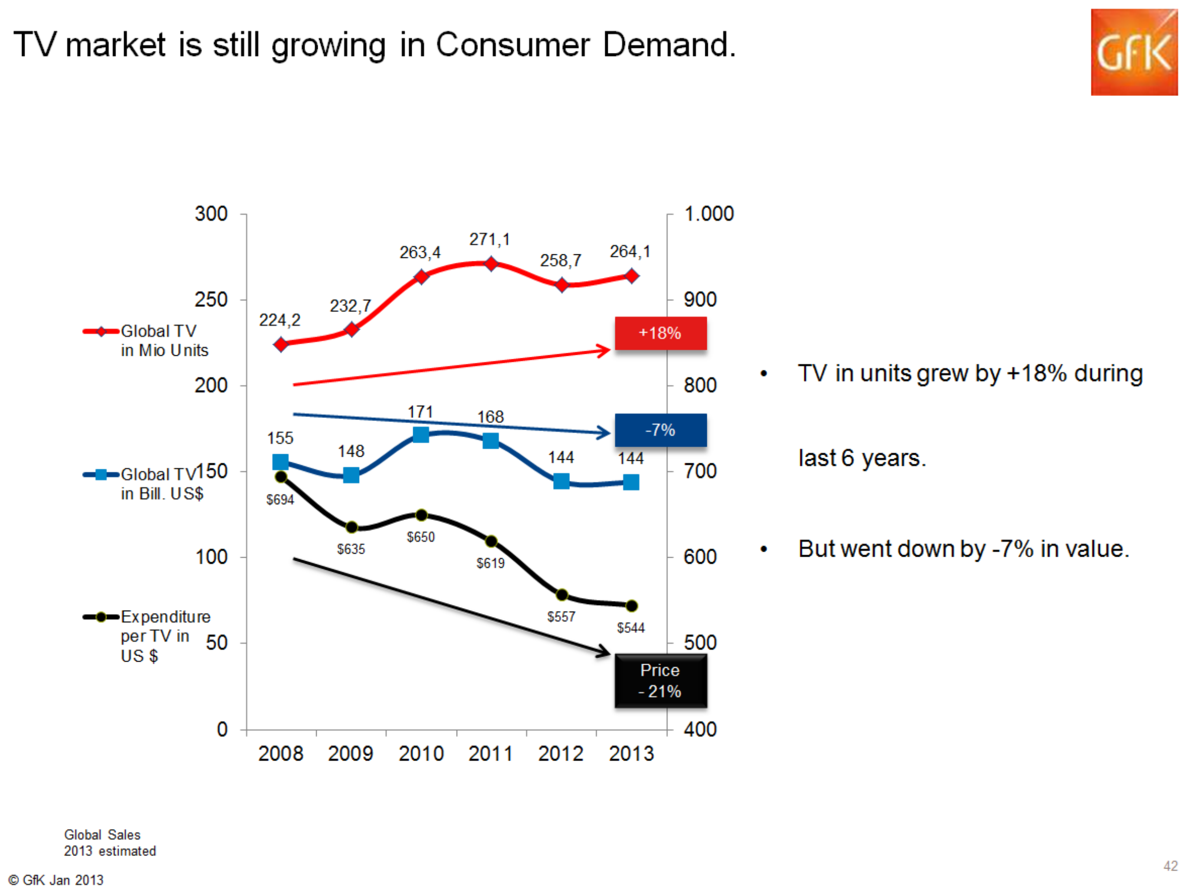

Figure 3: Source: GfK Retail and Technology in cooperation with GfK Boutique Research

Driven by Central and Eastern European countries (incl. Russia) with lower household saturation, the European LCD-TV Market in total is slightly growing as well. If we expand the look onto central Eastern Europe the Russian market is expected to overtake the leadership in sales volume from Germany in 2013. Western Europe is stabilizing itself on a relatively high consumption level with Germany as the biggest market, followed by UK and France. The continuously high sales volume is supported by accelerating replacement rates, e.g. in 2012, it was recorded that TVs in Germany were replaced after an average of 5.7 years, a strong contrast to the 11 years average of CRT (Cathode ray tube) TV sets.

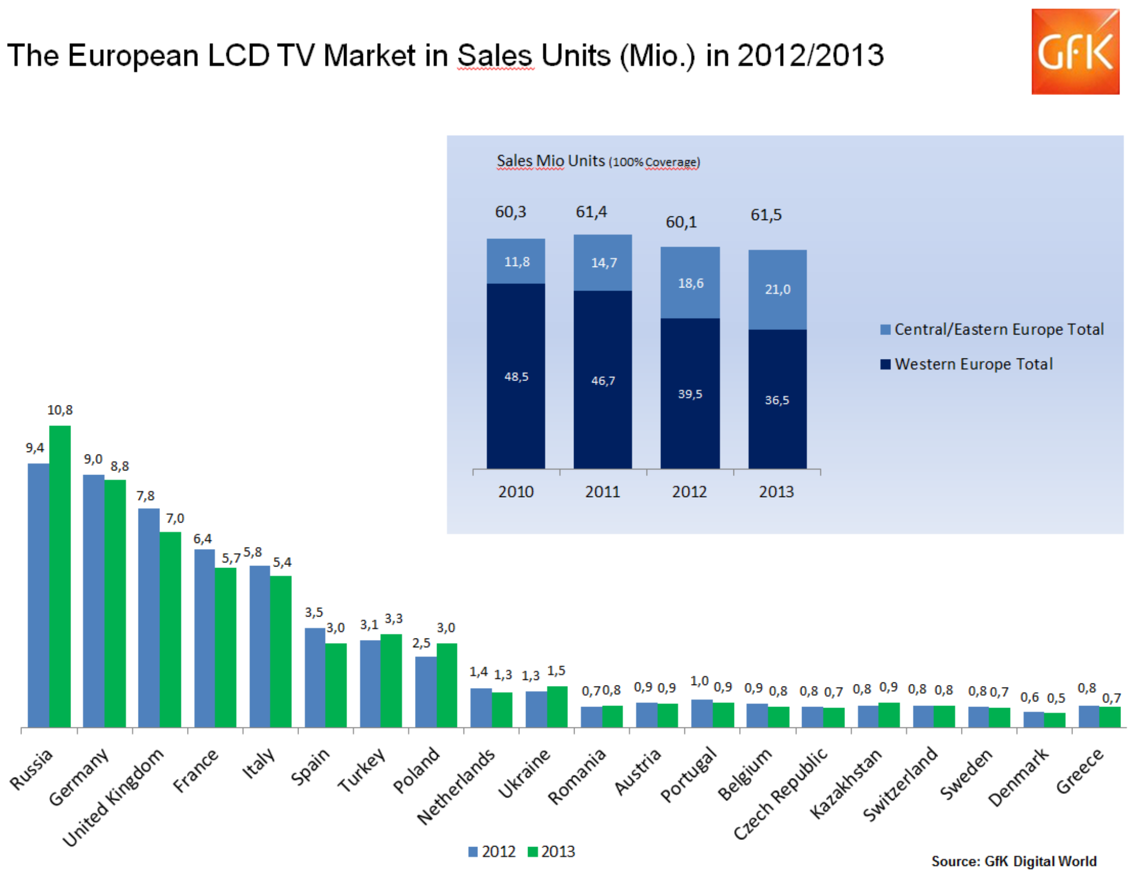

Figure 4: Source: GfK Retail and Technology in cooperation with GfK Boutique Research

The large scale transition to LCD TV followed by the rapid improvement of LED technology reduced the impact of increases in screen size and TV sales on total power consumption significantly. Thus although the number of TV sold from 2009 to 2013 was increasing the average energy consumption of this TV sets was reduced by 58% from 207 kWh/year to 87 kWh/year. LED backlite TVs already capture more than 80 % of the sales in EU 25 in May 2013. Moreover, the energy efficiency for Plasma TV's improved in the same time as well from a high level of 420 kWh/year in 2009 to an average consumption of 220 kwh/Year in 2013.

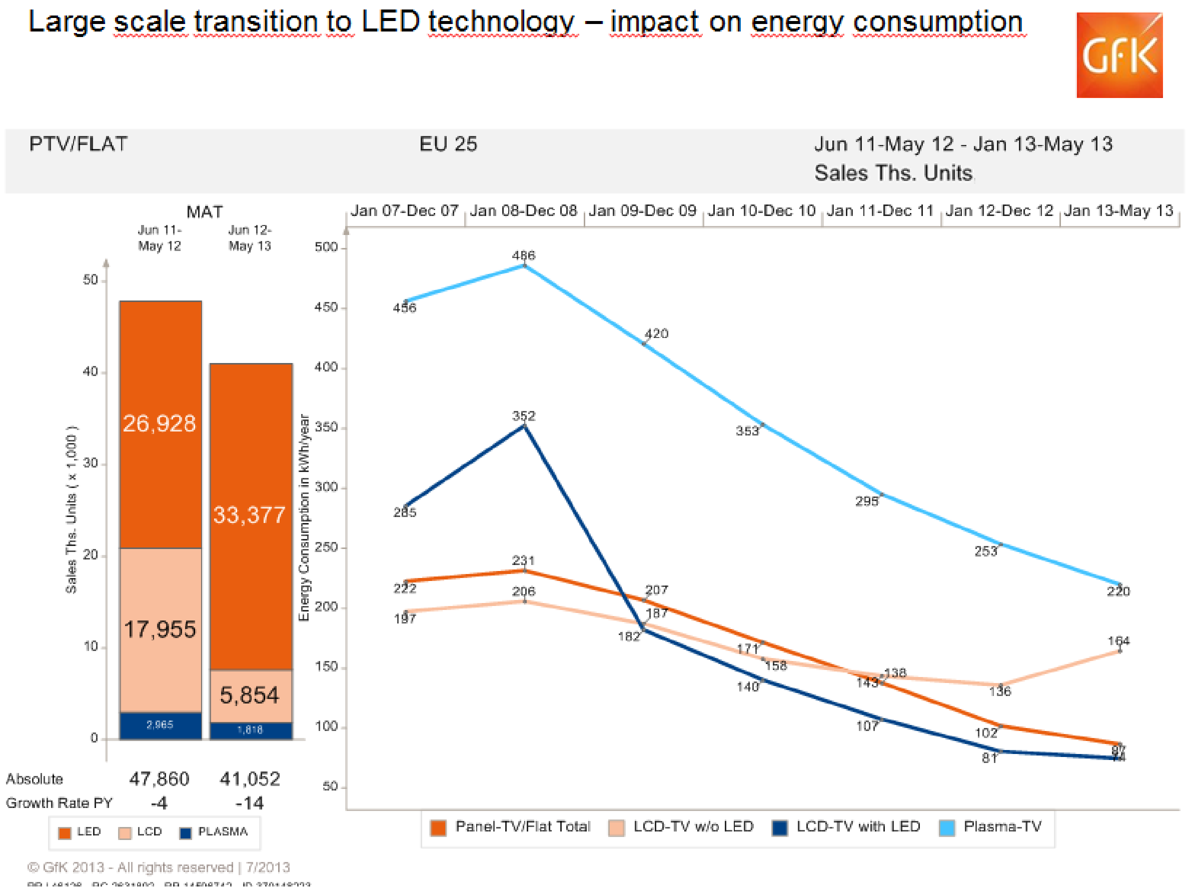

Figure 5: Source: GfK Retail and Technology

Further on, the shift towards LED technology negates the impact of trends in increasing TV sales combined with increasing screen sizes in total energy consumption. In Europe 25 the share of TV sets featuring a screen size of 40 inch or more greatly increased from 33,7% in 2009 to 52,8% in 2013. This trend is supported by resolution in 4K UHD as well as UHD resolution allow consumers to get closer to the TV for a more immersive, home theatre experience on big screens with more than 80 inch. In view of these facts, it becomes obvious that an improvement of the energy efficiency for TV's with increasing screen sizes is of high importance.

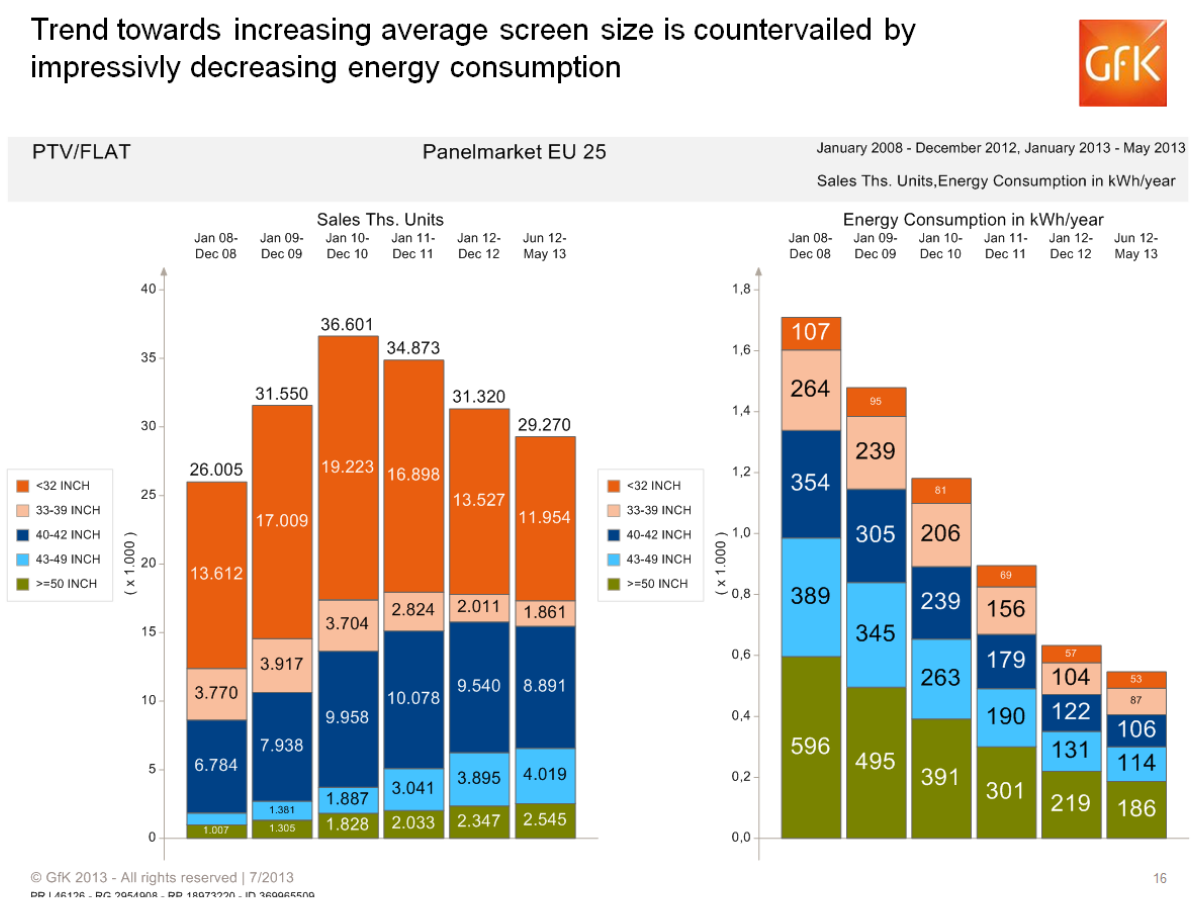

Figure 6: Source: GfK Retail and Technology

However increasing TV usage time exacerbates the necessity of energy efficiency. Several recent indicators corroborate this statement. Technical challenges redefine television as a product: Smart TVs (connected TV) will be established as a mainstream technology and a new overarching trend in life style and TV usage. It is difficult to quantify the Smart TV functionality and its effect in usage that it has to extended on-mode hours, but the increased household saturation with Smart TV and 3DTV may stimulate consumers to buy larger screens and extend viewing hours.

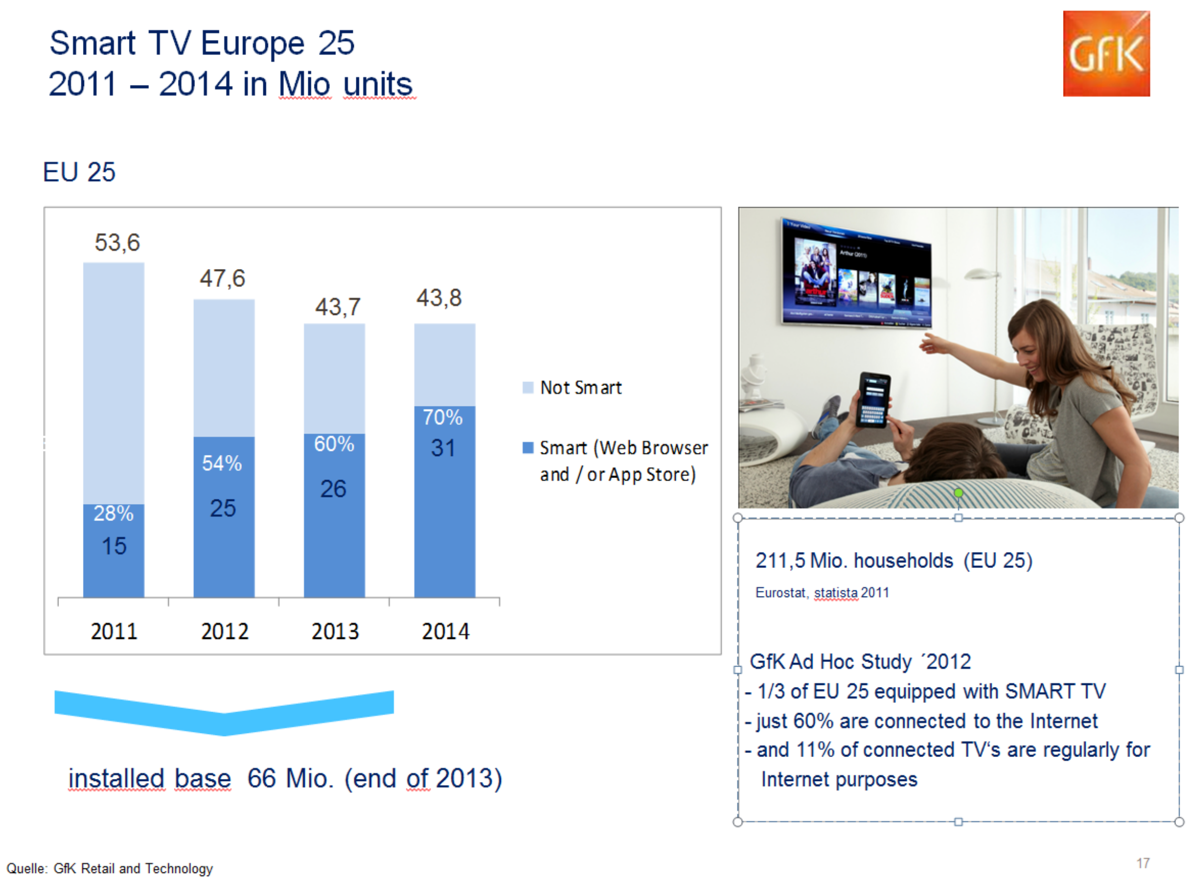

Figure 7: Source: GfK Retail and Technology, GfK Boutique Research and GfK Household Panel (Consumer Experiences)

On the other hand due to a higher degree of comfort the number of TV sets per household is a major factor that will increase the viewing hours with multiple TV's running in the future. Due to the "Statistisches Bundesamt", Wiesbaden counted for Germany in 2005 1,5 TV's per household while the number in 2012 grew to 1,7 TV's attended with a growing number of households (especially single households) itself. The majority of the new sold TV's are already equipped with Smart functionalities (web browser/app store). Smart TVs are expected to consume more energy compared to non-connected TVs. But due to the fact that these devices represent the newest development in the industry the energy consumption level of Smart TV's shows also the best possible performance in energy consumption – in total below the average of non-connected TV's.

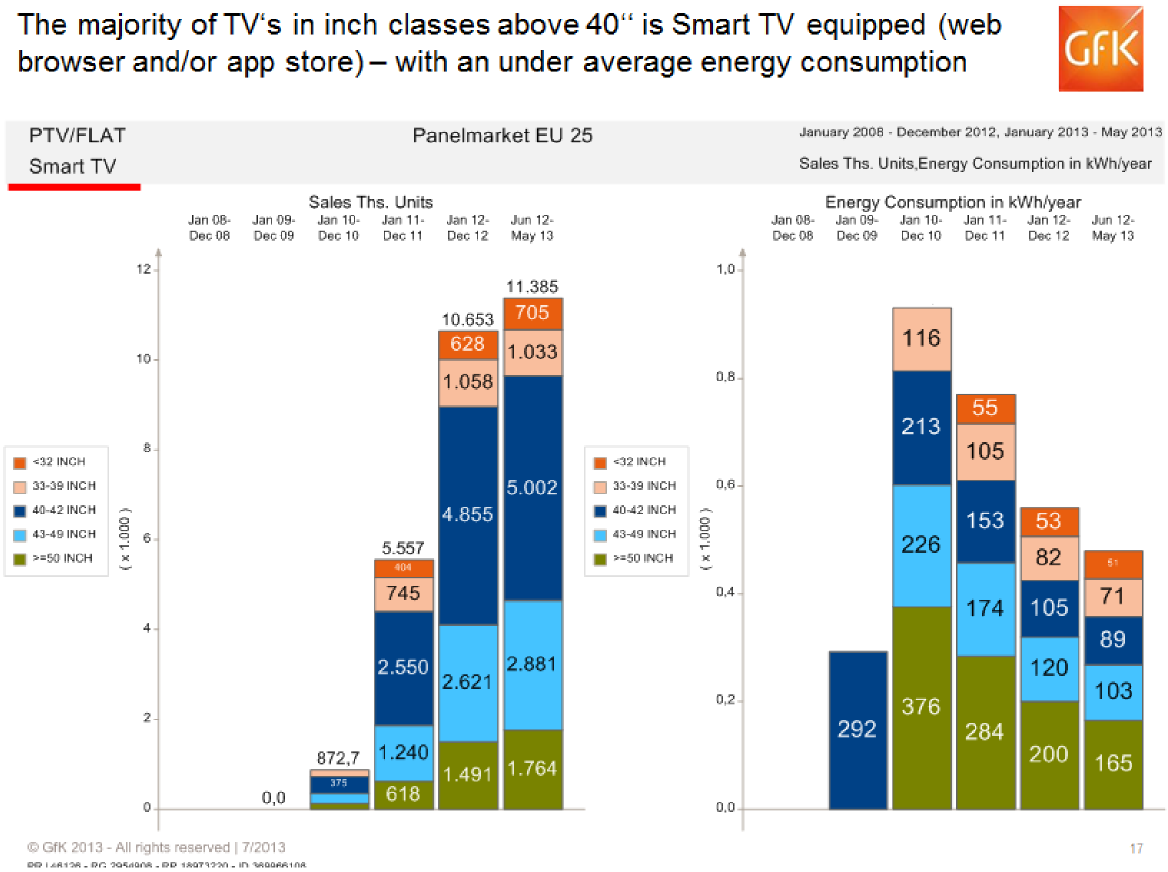

Figure 8: Source: GfK Retail and Technology

To make these trends transparent to end consumers on single model level it is possible to quantify the share of energy cost occurring during a TV life cycle of 7 years and 4 hours on mode - multiplied with the respective price development per kWh in the countries. The Top 5 products in EU 25 show a tremendous difference between 2010 and 2013 and in inter-model deviation within the same inch class regarding additional energy cost. But generally the share of energy costs shows a shrinking tendency – although energy prices increased significantly during the same period. For that reason the transparency of energy related information as provided by the energy label is essential.

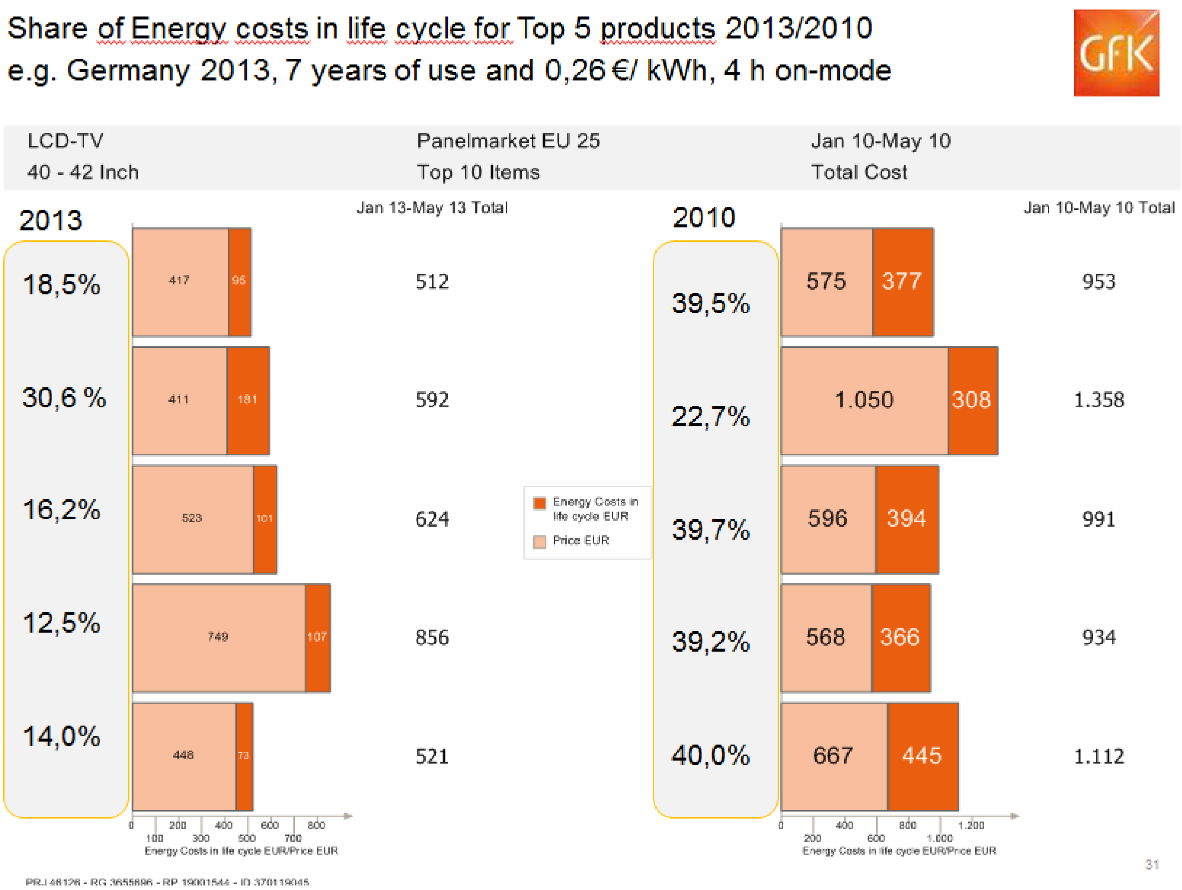

Figure 9: Source: GfK Retail and Technology and retail (end user) prices for energy prices for households from EEP “Europe’s Energy Portal”

3. Distribution of the TV Energy Label in Europe; importance and evolution of the different efficiency classes

The objective now is to provide initial information supporting the design of the new TV Energy label with results from GfK retail Panel one and a half year after the introduction of the mandatory use. GfK reports provide TV market data according to volume, price, and screen technology, several features like screen size, energy consumption, energy label, brands and countries for every single model sold.

A correct implementation of the EU Ecodesign directive saves energy, and supports an environmental friendly consumer purchase decision. Currently the Ecodesign for TV does not deliver its full potential. Results of GfK Retail and Technology are showing a share of 16-18% of the sold devices without any Ecodesign identification (Energy Label) in EU 25. This result is underlined by another study of the German “Verbraucherzentrale Rheinland Pfalz” (Mainz, 6.5.2013, Elke Dünnhoff “Energy designation on technical consumer goods – results of the second market checking December 2012”). According to the results of this study 25% of the TV’s offered in traditional shops (no Internet) haven’t been labelled one year after the introduction of the mandatory use of the new Energy label. For models introduced before Nov 2011 to the market the label is not mandatory – but it is questionable if the long transition periods support the market transparency. A limitation of the transition period up to a maximum of one year would improve the situation significantly.

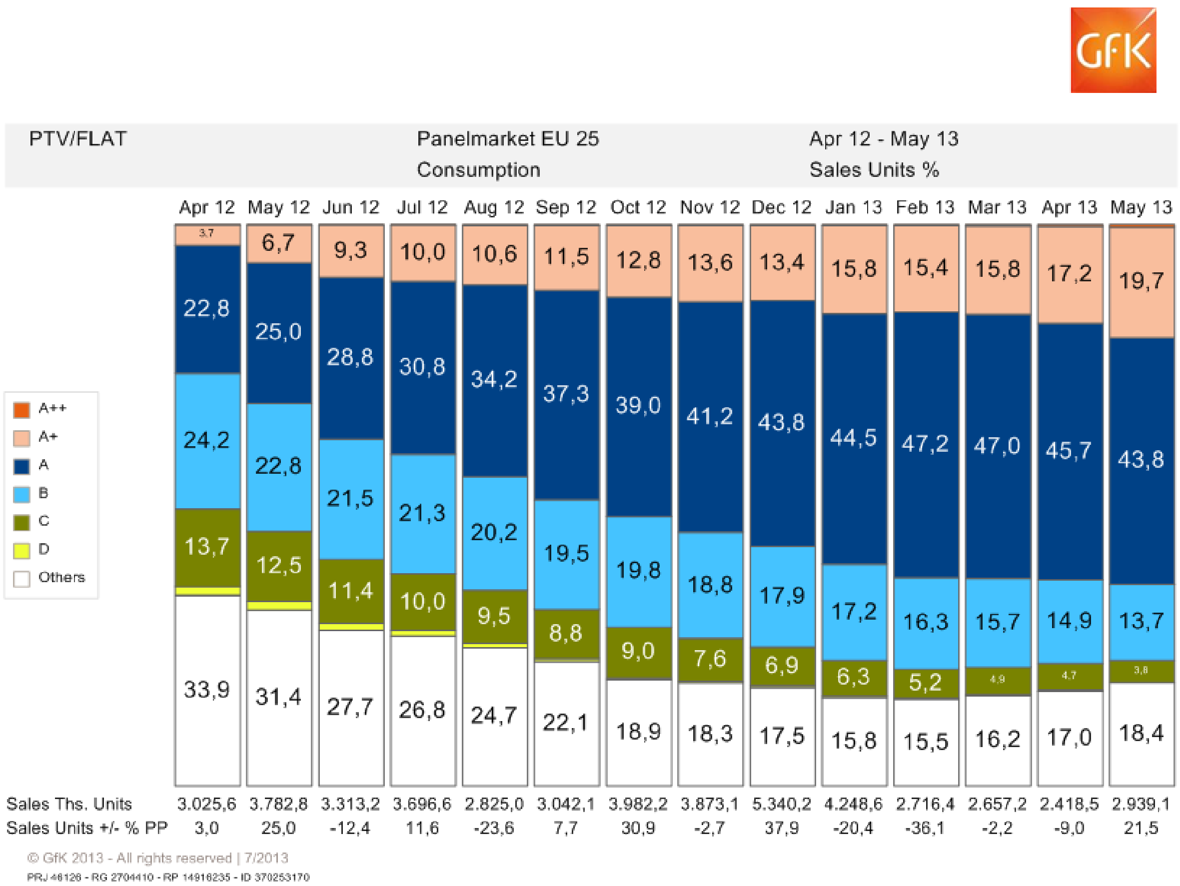

Figure 10: Source: GfK Retail and Technology

Already 17 months after the introduction of the new mandatory TV Ecodesign 45,7 % of the products use label A and 17% A+. Products within category C, D, F and G are underrepresented or missing completely. Though these findings are positive, they also raise the question “are the Ecodesign parameters already outdated?”

GfK Retail and Technology delivers representative results of the use of the new EU Energy Label with country specific developments and the associated different pace in transformation dynamics.

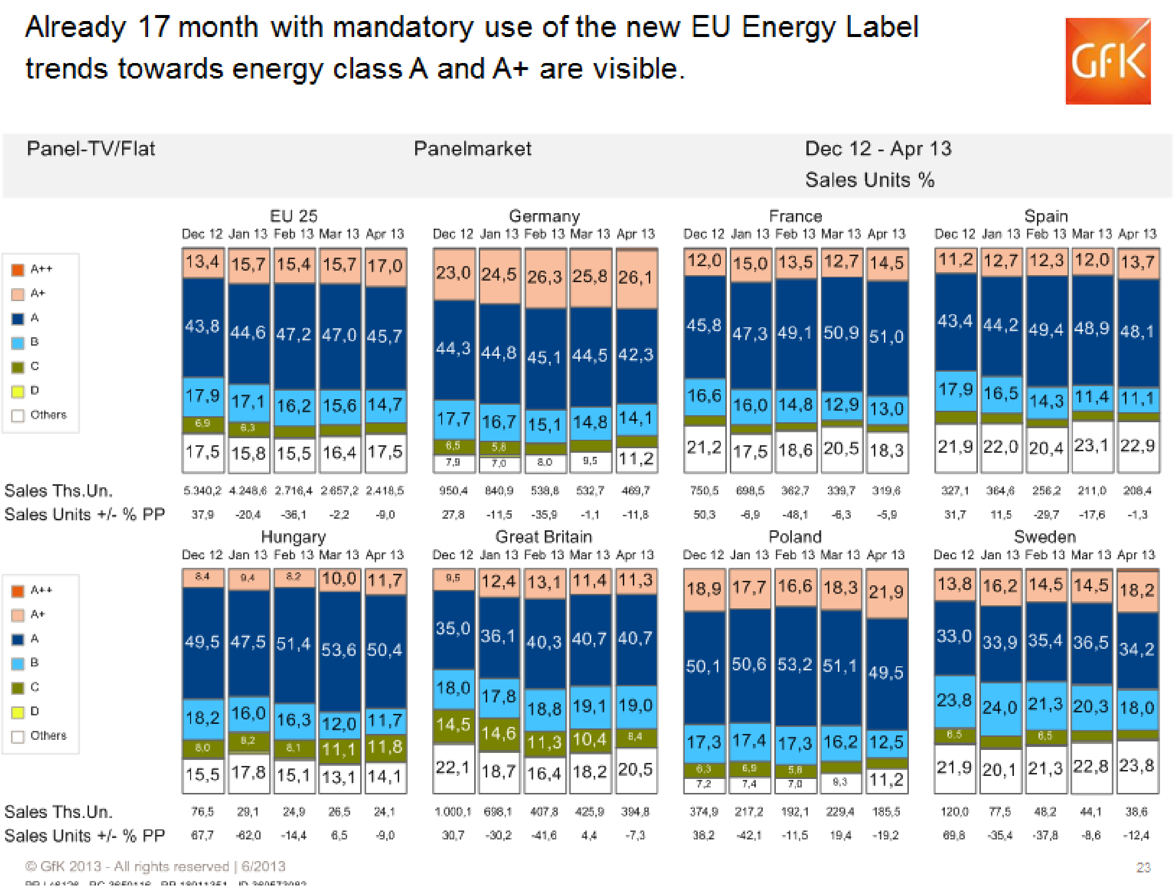

Figure 11: Source: GfK Retail and Technology

The Top 5 manufacturers produce more than 90 % of the sold LED TV's in EU 25 (March-May 2013). Some major brands provide more efficient LED TVs at lower prices on a similar equipment level. For that reason it is recommended to raise the awareness among the industry on the full power of the Ecodesign directive with its marketing advantages.

However the industry shows more interest in developing products with bigger screen sizes as average end consumer prices are increasing with bigger screen sizes. From the point of view of energy efficiency it would be highly desirable to have a price variance and competition within one inch class depending on absolute energy consumption.

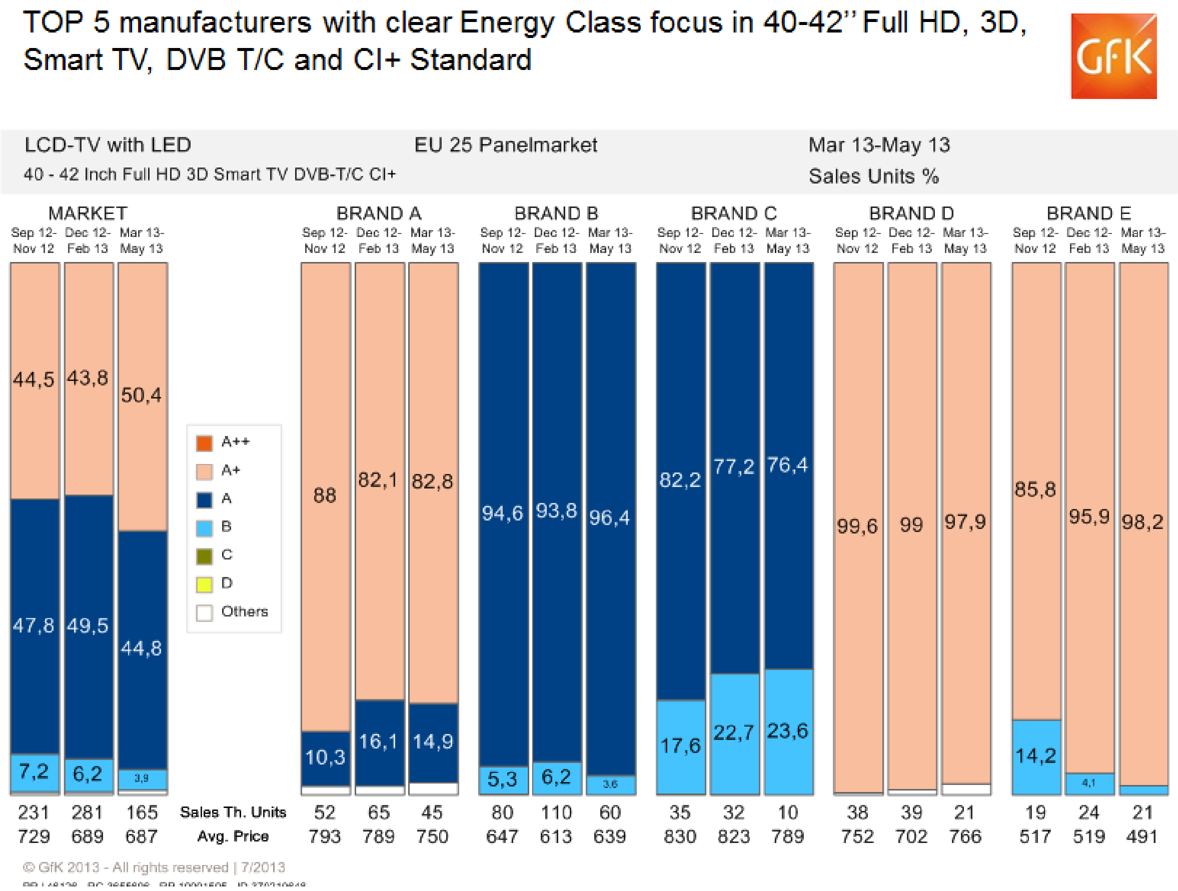

Figure 12: Source: GfK Retail and Technology

The Energy efficiency index per class is defined as specific relation between screen size and consumption and some other functionality like HD recording, integrated receivers or automatical brightness control. However it is obvious that in higher inch classes the share of A+ and better devices increases significantly as the index of the relation between inch size and energy consumption can be archived much easier. The inch class 32''-39'' has a share of 14,8% A+ while 50+'' has a share of 62,4% A+ devices. If we compare the energy consumption of Energy class A+ in absolute terms for inch size 32 -39 with 54 kWh/year and above 50'' with 118 kWh/year we come to a wide possible range of absolute consumption within one energy class and much more impressive – a positive correlation between "high" Energy efficiency and increasing TV screen size. As bigger the screens and the absolute consumption as better the Energy efficiency class. Do we really want to encourage customers to buy products with higher absolute energy consumption? Products with higher absolute energy consumption shall not achieve easier good Energy Efficiency classes than smaller products. The absolute consumption in kWh/year is the criteria with higher importance – it is not enough to look onto efficiency classes.

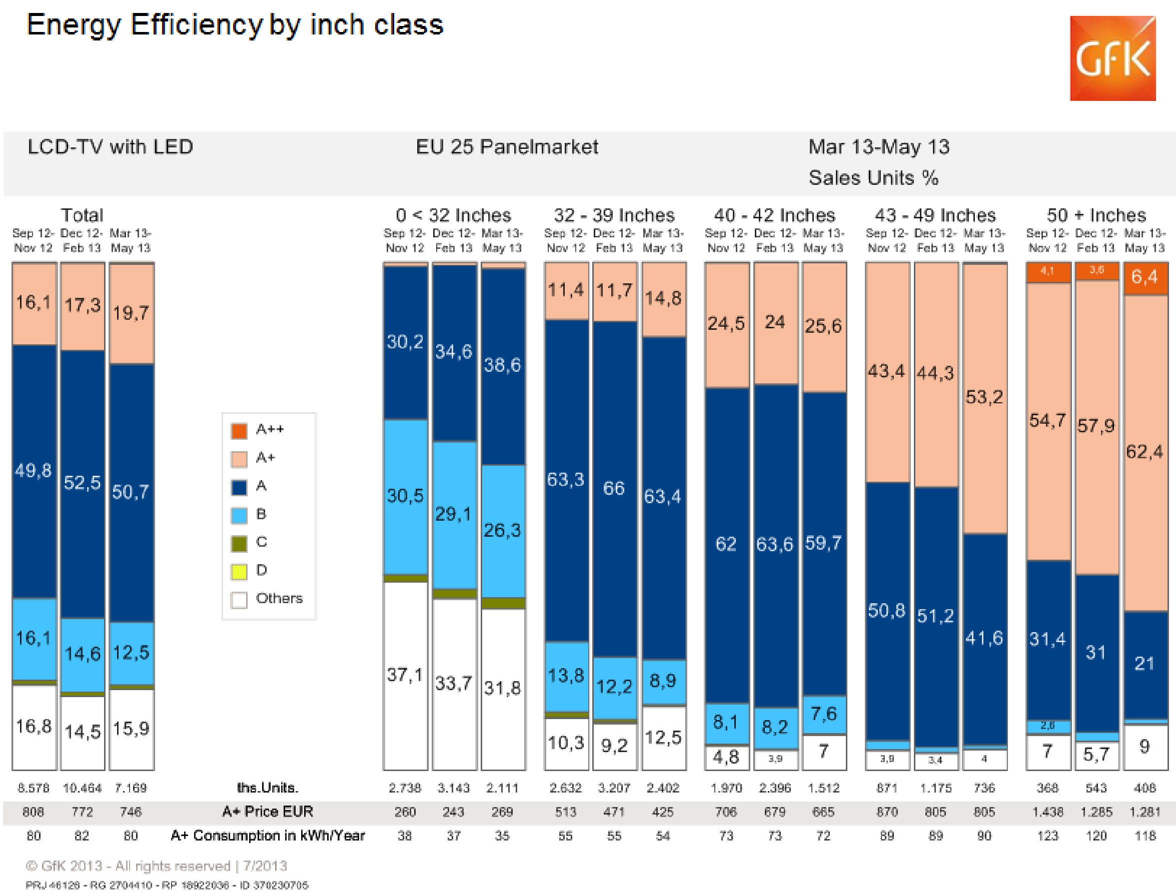

Figure 13: Source: GfK Retail and Technology

Summary and conclusions

- The TV sales volume and the screen sizes will show further increase in the future. In the medium term energy costs will increase in parallel. For that reason it is necessary to track recent technological developments with retributive influence on increasing energy consumption and support consumers in their purchase decision with clear product information on Ecodesign.

- An improved and quicker European market monitoring before and after the setting of minimum performance standards would support the Ecodesign directive significantly.

- To tap the full benefits and potential of the new Ecodesign directive for TV it is necessary to avoid too complex and in-transparent regulations in the implementation and establishing an efficient market control.

APPENDIX

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2. Relevant Topic and Related Technology

“6. Standards and Labels”
“3. Consumer Electronics”

3. Abstract with Key Words
Page 1

Appliance Minimum Energy Performance Standards and Labelling (S&L) Programmes: Whither Thou Sub-Saharan Africa?

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Abstract

Standard and labelling programmes are not yet a mainstay in most of Sub Saharan Africa (SSA). The barriers to the uptake of S&L programmes in SSA are identified to be: associated programme costs, lack of favorable regulatory environment and a weakened market for energy efficient appliances/equipment. Increased electrification, increased appliances/equipment ownership as well as the effects of regulations applied in the trading partners are considered to be the main indicators for instituting S&L programmes in SSA. Harmonization of Standards and Labels within and across regions is proposed to be the tool for accelerating the uptake of S&L programmes in SSA. Consumer awareness is considered key to the success of S&L programme implementation in SSA and the use of radio and mobile phones for educational and awareness campaigns is suggested.

Introduction

Standards and Labelling (S&L) is a market transformation programme and many countries of the world have implemented such programmes [1]. Transformation of the electrical appliance/equipment market is derived from the removal of energy inefficient appliances and/or equipment from the market. Well designed and implemented S&L programmes have the following advantages [1]:

- Large electrical energy savings
- Limiting energy growth without limiting economic growth
- Require change of behaviour of manufacturers and retailers rather than the whole population of consumers of electricity

Sub-Saharan Africa is a region in the African continent south of the Sahara made up of 51 countries and has a population of 840 million people and approximately 148 million households [2]. Sub Saharan Africa is made up of the 51 countries that are listed in table 1. Sub-Saharan Africa is a vast area with wide differentiations in economic development, industrialisation levels, agricultural activity, mining activity, political stability and infrastructural development.

The electrification status for Africa as reported by International Energy Agency (IEA) [3] is presented in table 2. As seen in table 2, it is evident that the power sector of the Sub-Saharan Africa is immensely underdeveloped when compared to other regions of the world. The electrical power supply in most Sub-Saharan countries is unreliable with frequent power cuts and high dependency on emergency back-up diesel generators [4].

There is a broad relationship between electricity consumption and levels of economic development in any particular country [5]. It has been determined that electrification levels, household income and urbanisation affect the ownership of domestic appliances. Therefore, in a broader sense, figures in table 2 suggest low electricity end-uses in Sub Saharan African countries which in turn imply lower electrical appliance ownership levels.

Table 1: Sub-Saharan Countries

1	Angola	15	Equatorial Guinea	29	Mauritania	43	South Africa
2	Benin	16	Eritrea	30	Mauritius	44	Southern Sudan
3	Botswana	17	Ethiopia	31	Mozambique	45	Swaziland
4	Burkina Faso	18	Gabon	32	Namibia	46	Tanzania
5	Burundi	19	The Gambia	33	Niger	47	Togo
6	Cameroon	20	Ghana	34	Nigeria	48	Uganda
7	Cape Verde	21	Guinea	35	Northern Sudan	49	Western Sahara
8	Central African Republic	22	Guinea-Bissau	36	Réunion	50	Zambia
9	Chad	23	Kenya	37	Rwanda	51	Zimbabwe
10	Comoros	24	Lesotho	38	Sao Tome and Principe		
11	Congo (Brazzaville)	25	Liberia	39	Senegal		
12	Congo (Democratic Republic)	26	Madagascar	40	Seychelles		
13	Côte d'Ivoire	27	Malawi	41	Sierra Leone		
14	Djibouti	28	Mali	42	Somalia		

Table 2: Electrification Status in Sub-Saharan Africa [3]

Region	Population without Electricity (Millions)	Electrification Rate (%)
North Africa	1.6	99
Sub-Saharan Africa	585.2	30.5
Africa	586.8	41.8

In Sub-Saharan Africa region where there are chronic electric energy shortages [4] [5] it would be advantageous to take on board S&L programmes to conserve electrical power. Even though currently the levels of electrification are low suggesting low appliance penetration levels this is expected to change due to the new infrastructure build-up in SSA. Furthermore, if the approach of regionalism is taken into consideration then ownership levels and market sizes grow significantly to warrant the introduction of S&L programmes especially because regional power sharing pools already exist.

This paper will discuss the state of S&L programs in Sub-Saharan Africa and point out the barriers to the uptake of S&L programmes in Sub-Saharan Africa. The indicators for S&L programs in SSA will be presented as well as proposals for the way forward to accelerate the uptakes of S&L programs in SSA.

The State of S&L Programs in Sub-Saharan Africa

The first country based governmental work towards S&L was in Poland in 1962 and was then followed by work in France in 1966 [1]. Between the years 1966 and to date many other countries in Europe, USA, Canada, Australia, Japan and many others as documented in [1], have implemented S&L programmes for different appliances [1]. Different countries have implemented either voluntary or mandatory S&L programs as they have found it befitting to their countries. The progress and success of many of these programmes have been widely reported. The S&L programme in European Union (EU) countries is an example of a strong and thriving regional programme.

The uptake of S&L programmes in Sub-Saharan Africa is pictorially presented in figure 1.

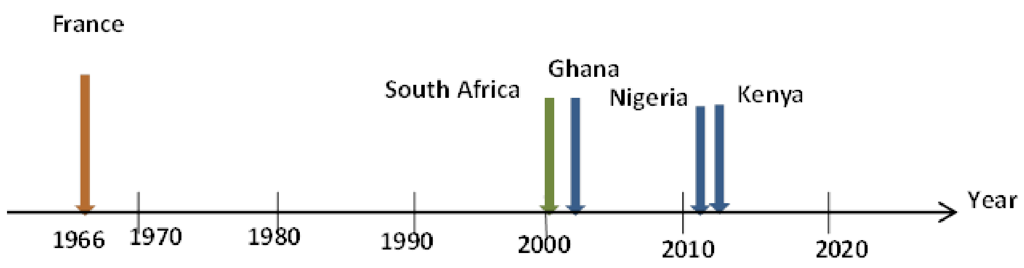

Figure 1: S&L Program Uptake in Sub-Saharan Africa

As indicated in figure 1, the uptake of S&L programmes in Sub-Saharan Africa has been very slow. Africa appears in the activity map of S&L programmes beginning in 2000. During the high activity years between 1960 and 2000 when S&L programmes were established and implemented in most European countries, USA, Australia, Japan, Brazil, India to mention a few, there was no activity in SSA countries. S&L programmes have been initiated in the following SSA countries: South Africa (2000), Ghana (2002), and most recently in Nigeria (2011) and in Kenya (2012). The programme in Kenya is expected to be extended to the rest of East African countries of Tanzania, Uganda, Burundi and Rwanda.

The programme initiated in South Africa has gone through different phases and currently the programme is being re-looked into and being re-established to cover the following appliances: Refrigerators, dish washing machines, clothes washing machines, electrical ovens, deep freezers, and geysers. The S&L programme in South Africa has not yet been able to bring forth much result, and Ghana is the only Sub-Saharan country in which S&L programme are said to have been successfully implemented.

In general, S&L programmes are non-existent in 47 countries of SSA; S&L programmes are at an infant stage in Nigeria and Kenya; S&L programmes have hardly been implemented and therefore unqualified in South Africa; and have been implemented successfully for one appliance group (refrigerators) in Ghana. In October 2012, ECOWAS Energy Efficiency Policy was adopted and an S&L technical committee was formed. This is evidence of the first steps towards regionalisation in formulation and implementation of S&L programmes in SSA.

Fall [6] summarizes the state of S&L programmes in Africa as follows:

“So far, labeling and minimum energy efficiency (performance) standards (MEPS) for appliances and equipment, although have proven to be one of the most essential policy options in developed countries’ portfolio for energy efficiency and climate change mitigation programmes, are not very common in Africa, and rarely mandatory – and for most countries they do not exist at all in any economic sector.’’

Figure 1 also indicates that SSA is way behind other world countries in the uptake of S&L programmes. This is an advantage as well as a disadvantage. It is an advantage because SSA has the opportunity to learn from other well-established programmes and therefore avoid many pitfalls of badly designed and implemented programmes [7]. It is a disadvantage because countries without S&L programmes can become both dumping grounds as well as second-hand markets for appliances/equipment not meeting the program standards in countries where S&L are implemented and rigorously regulated [1][8].

The uptake of S&L programmes is low and slow in Sub-Saharan Africa countries, hence the need to answer the question “What are the barriers to the uptake of S&L programmes in Sub-Sahara African Countries?”

Barriers to the Uptake of S&L Programmes in Sub-Saharan Africa

The barriers to the uptake of S&L programmes in Sub-Saharan Africa are mainly due to associated programme costs, lack of favourable regulatory environment and a restricted market for energy efficient appliance/equipment.

Associated S&L Programme Costs

The process of developing and implementing well designed energy efficiency labels and standards require allocation of legal, financial, physical and institutional resources [1], for example in the USA the average annual expenditure has been 5.5 million. In the period from 1960's to mid-1990's, on average real GDP growth performance in Sub-Saharan Africa was reported to continuously deteriorate [9]. This is the same period where in other countries, S&L activity was at its peak [1]. The uptake of S&L could have not been a priority to the individual governments in SSA amidst declining GDP growth, if all the associated costs of designing and implementing S&L programmes are considered.

The running of S&L programmes requires well trained personnel to carry out;

- Appliance testing and certification
- Programme evaluation
- Programme monitoring and enforcement

Capacity building should be instituted to support S&L programmes and this adds to the programme costs. The success of S&L programmes hinges on the capacity to carry testing of appliance/equipment in specialized testing laboratories, which can be national or international institutions. The cost of developing and equipping a national testing facility or outsourcing the testing component of S&L programme are significant. Development of capacity for monitoring, enforcement and evaluation of S&L programmes adds another cost component to the programme.

Generally, in most SSA countries S&L programme costs would compete with other social/economical/infrastructural development agenda. For example, it would be difficult for S&L programmes to be given priority in national budgetary allocations ahead of education, health or infrastructure development especially in a period where the GDP growth was continuously declining. The costs outlined rendered the implementation of S&L programmes prohibitive to most SSA countries. This suggests why where S&L programmes have been implemented in SSA; there has also been a significant financial support of the programmes by international organizations.

Lack of favourable regulatory environment

The establishment and implementation of a successful S&L programmes require a favourable regulatory environment. The presence of supportive national energy policies as well as national energy efficiency strategies is important. All existing energy efficiency labelling programmes in SSA are national initiatives, driven by the requirements of national government policy. In the absence of such regulatory environment it is not possible to institute S&L programmes. This is because by their very nature S&L programmes if mandatory have an enforcement component which must be supported by appropriate enacted national regulation and legislation. In most SSA countries such environment is absent and where it exists it has not yet been put into use.

Weakened Energy Efficiency Appliance/Equipment Market

S&L programmes work well in countries where there is well developed manufacturing industry of the appliances/equipment under programme consideration and/or high appliance/equipment penetration levels. This necessitates that the local manufacturing companies equip their production lines for the production of energy efficient appliances/equipment to feed the local market. The high penetration rates of the appliance/equipment ensure a market that can meet the demand for energy efficient goods.

In SSA, the appliance market to a great extent is overwhelmed by non-efficient appliances/equipment or second hand appliances/equipment selling at very low prices. The sustainability of these markets is underlined by the affordability of appliances/equipment and consumers who are mostly only concerned by the price and the functionality of the appliance. Unfortunately the price of energy efficient appliances/equipment cannot compete with the price of new but extremely affordable or second hand appliances. In such a market environment, it is difficult to introduce S&L programmes because of a weakened energy efficient appliance/equipment market.

Appropriateness of S&L in Sub-Saharan Africa at the Present Time

Sub Saharan Africa is seen as a region that will experience fast changes in economic activities in the coming years. The increased economic activity is linked to two main developments namely political stability and new discoveries of mineral, natural-gas and oil deposits. It is expected that the economic developments will be coupled with infrastructure and social developments. In the fore front is the development of the electrical power infrastructure to improve the supply, quality and reliability. It can therefore be said that the present time is appropriate for SSA to embark into S&L programme due to the following:

Expected Increased Electrification Rates

Rural electrification rates in Sub-Saharan Africa countries are projected to increase to 50% by the year 2030 due to government power expansion projects facilitating grid and off-grid household connections [4][5]. There has been the establishment of regional power pools [11] [4] i.e. the South African Power Pool (SAPP), the Eastern Africa Power Pool (EAPP), the Central African Power Pool (PEAC) and the Western Africa Power Pool (WAPP) in SSA. Reliable electrical power infrastructure is required in SSA to fuel and sustain the projected levels of economic development activity envisaged in the region. The expansion in power generation will have to be accompanied by energy efficiency measures in generation, transmission, distribution and in all end-uses. This is unavoidable because energy efficiency improves energy security, increases competitiveness and reduces green gas emission [6] [10]. Energy efficiency (EE) measures will ensure enhanced reliability and sustainability and it is no doubt that EE measures are the most cost effective intervention and must be mainstreamed in energy delivery and usage.

In the period between 2000 and 2010, the output from African manufacturing sector roughly doubled [12]. With the increase in electrification in SSA it is expected that manufacturing activity will intensify. However, Africa has the highest energy per unit of economic output when compared to other countries of the world. The urgency of energy efficiency in SSA is further indicated by this apparent inefficient use of energy in manufacturing processes in the region.

Increase in Domestic Appliance Ownership

An increase in appliance ownership levels is a natural consequence of increase in electrification rates. At household level, rise in rural electrification rates will bring about increase in ownership of electrical household appliances as well as installation of electrical lighting. The increase in appliance ownership is also linked to household income. It is reported that, 22 countries in Africa with a population of 400 million people are already middle income countries and by 2025 with modest growth and stability, another 10 countries with a population of 200 million will attain the status of middle income countries [13]. Furthermore, SSA is quietly but rapidly becoming a significant market for technology-based consumer products [14]. Sub-Saharan Africa countries will become the world's largest appliance market of the future because in the rest of the world economies household appliance ownership rates are rapidly reaching or are already in saturation levels. The increase in appliance ownership in SSA implies an increased electrical load in grid or non-grid connected households and highly indicates for S&L programmes.

Regulations Implemented in SSA Major Trading Partners

Most of the products that are covered in Directives and regulations passed in the trading partners of SSA are traded globally. As expected, such directives impact on the global trading dynamics and SSA is not immune to the impacts.

The European Union Energy related Produce (ErP) Directive

In the European Union (EU) region S&L activities have included work on EU Directives. The Energy related Products (ErP) directive [15] for example replaced the Energy using Products (EuP) directive in November 2009. The ErP directive provides a framework for establishing minimum eco design requirements for energy using and energy related products. The ErP directive widens the scope of the EuP directive of 2005. The objectives of ErP directive are the following [15]:

- Decrease the environmental effects and to promote environmental sustainability
- Reduce greenhouse gas emissions
- Reduce the damaging environmental impacts of products at the end of product life
- To ensure free-trade in energy using and energy related products.

Implementing measures (IM) have been provided on the following classes of products [15]: Circulators, electric motors, household refrigerators, external power supplies, non-directional household lamps, simple set top boxes, standby off mode, street and office lights and television sets. This implies that any of the products covered in the scope of the IM can be sold on the EU market only if the product meets the ErP directive. In essence, this directive closes the EU market for non-complying products. Products that cannot enter the EU market are sold elsewhere in other markets where regulation is lax. SSA has unfortunately become a favourable destination of such products as it continues to lag behind in S&L programmes.

The ErP directive is also about the life cycle cost on energy and the environment of a product, and it directly points to the cost of energy and cost to the environment in manufacturing processes. Manufacturers are required to realign manufacturing operations to the directive. This has resulted in some transnational corporate giants in the developed countries shifting their energy consuming and highly polluting operations to developing countries under the disguise of investments. In general the developing countries bear both the cost of non-efficient dumped products as well as the costs of high energy consuming and high polluting production operations. To avoid these costs due to dumped products and dumped production processes, SSA should become active in S&L programmes.

Waste Electrical & Electronic Equipment (WEEE) Directive

The WEEE directive of January 2003 is an EU directive that seeks to reduce the quantity and harmfulness to the environment by electrical and electronic equipment and materials [16[17]. The implementation of the WEEE directive has brought about the export of equipment to other countries where the goods are recycled or re-used. The exported equipment falls into two groups i.e. properly declared and described equipment and grey market export where equipment and components are incorrectly listed as Green list Waste and shipped to non-OECD countries [16].

Equipment exported as grey market goods finds its way mostly to developing countries where the equipment is sold as second hand equipment or as spare parts. These equipment or parts are mostly old and would in almost all cases be very energy inefficient and are not environmentally friendly. Re-introducing such equipment/parts into the market results in increased energy use and increased green gas emissions. Unfortunately, SSA has become a major dumping ground of non-compliant or grey appliance/equipment fuelled mostly by the non-existent energy of appropriate standards and regulations.

Conclusion

In the absence of S&L programmes, Sub-Saharan Africa will continue to be a dumping ground for non-efficient and grey appliances/equipment and the recipients of energy inefficient and highly pollutant manufacturing/industrial processes. In its quest to build and increase electrical power generating, transmission and distribution capacity, SSA cannot afford not to conserve the energy through energy efficiency practises.

Rural electrification in SSA in areas far away from grid is expected to be achieved through appropriate renewable energy technologies. S&L programmes will be critical for the sustainability of the rural power supply through the use of energy efficient lighting and appliances. In urban areas the penetration of electrical and electronic appliances/equipment will continue to grow at a much higher pace than the provision of reliable supply. In general, Sub-Saharan Africa can no longer push back the active design and implementation of S&L programmes.

The Way Forward for S&L Programmes in Sub Saharan Africa

The steps for the successful design and implementation of a sustainable S&L programme are outlined to include the following seven steps [1]:

- Decide whether and how to implement S&L
- Develop a testing capability
- Design and implement a labelling program
- Set minimum energy performance standards
- Design and implement a communication campaign
- Ensure programme integrity
- Evaluate S&L program

It is proposed that there be an S&L programme for SSA with the following objectives:

- Increase consumer awareness on the energy efficiency appliances/equipment purchase and raise energy efficient appliance/equipment use behaviour
- Eliminate inefficient models on the market through appropriate incentives to importers and consumers.
- Avoid the importation of new or grey appliances/equipment that has failed to meet the set minimum energy performance standards for new/used appliances/equipment
- Avoid industrial investments that import highly inefficient and highly polluting manufacturing operations into SSA

These objectives can be met through the following proposed considerations bearing in mind the seven steps outlined above for the design and implementation of S&L programmes.

Establishing Strong and Clear Political Legitimacy

The African Union (AU) through its two relevant organs i.e. AU Commission portfolio of Infrastructure and Energy and Specialized Technical Committee on Industry, Science and Technology, Energy, Natural Resources and Economics should be at the fore front to prepare suitable S&L programs in Africa for the ratification by the Executive Council. Through these two organs, there will be coordination and harmonization of the programme in AU. This should then be followed by the work of establishing appropriate policies and regulations in the S&L implementation regions.

Implementation Level for S&L Programmes in Sub-Saharan Africa

Sub Saharan Africa is considered as one economic region and in most world economic analyses, and in statistical reporting's the figures captured are for SSA region. In AU and in particular inSub Saharan Africa there already exist economic regions namely [18]: Southern Africa Development Community (SADC), East African Community (EAC), Economic Community of West African States (ECOWAS), Common Market of Eastern and Southern Africa (COMESA) and Economic Community of Central African States (ECCAS). These economic regions create socio-economic and political stability which is conducive for trade and movement of goods resulting in enlarged market size. The resulting market sizes bring in a bargaining power to the economic regions. In some of the economic regions there are already customs unions and free trade which works well for a common market. Therefore, these existing economic regions can be defined to be S&L implementation regions.

Regional S&L programs are logical also because of the existence of power pools [11][4] in Sub Saharan Africa. The concept of regional S&L makes good sense because regional power pools are communities of countries where electrical power is sold and bought and the power grid is interconnected. If S&L programmes are implemented regionally, then regions would work together towards conservation of a common shared commodity i.e. electricity power.

The existence of economic regions [18] will give momentum to the implementation of S&L programmes in SSA. This is because regional programmes will bring in economies of scale in terms of programme implementation cost, institutional capacity, as well as the market size for the goods to be regulated. Considerations should be made for the economic regions to form the clusters in which common standards and labels are shared. The SSA S&L programme should like the Australian program take the least common denominator approach which holds all participating countries to the levels that are acceptable to the least progressive country [1]. This consideration could result in regional implementing agencies championed by the four countries which are at different stages of implementing S&L programmes i.e. Kenya in East Africa, Ghana and Nigeria in West Africa, and South Africa in Southern Africa. It is good to report that the ECOWAS Energy Efficiency Policy already exists since October 2012 and an ECOWAS centre for Renewable Energy and Energy Efficiency is in operation [26] [27] [28]. As ECOWAS paves the way ahead, this can be a great model from which to learn for the other economic regions.

Analyses Relevant for the Determination of Standards in SSA

In [1], several analyses are proposed in the process of determination of relevant minimum energy performance standards (MEPS). To carry out a proper and credible analysis, credible data is of great importance, and this is hard to come by in SSA. However, not all analyses are applicable to a particular S&L programme design. The question is which analyses are relevant for SSA?

There is a very small manufacturing component in SSA for most of the regions to benefit from a manufacturing analysis. The availability of credible data for engineering analysis is doubtful because of the existence of the second hand market for grey products whose energy performance data might be hard to find or trace. But also most of the new appliances sold in the SSA counties are without certification and therefore energy performance data for these appliances will also be difficult to gather especially because of lack of certification laboratories in the region and reliance on data from external international laboratories.

SSA countries are mainly importers of appliances/equipment into their local markets. The major stakeholders are the importers/retailers, consumers. This implies that the relevant analyses required for the S&L programme design & implementation will in most cases be a market analysis and a consumer analysis. It is assumed here that the data inputs for the two markets are not the same and this can be reflected in the analyses outputs only if separate data sets are used for the analyses. The market and consumer analysis should differentiate between new and used appliances/equipment to correctly differentiate between the two market\consumer sets. It is important to again stress that credible data is hard to find in most SSA and sometimes the data available can only provide limited insight.

The second hand market serves a purpose to its customers. The objective of S&L programmes should be to regulate the second hand market and do away with the worst energy performing goods as dictated by the MEPS to be set. The objective of S&L programmes should not be to close down this market especially because of affordability to consumers.

Appliances/Equipment for Consideration for S&L programmes Implementation

The appliances to be considered for S&L programmes should be those with [1]:

- Potential for energy-efficiency improvement
- Adequate ownership and turnover
- Coverage by test procedures
- Energy efficiency regulations in other parts of the world
- Energy-labelling schemes

It is assumed here that the impact on total energy demand should be measured as an overall impact due to all the appliances/equipment in the programme rather than as an individual contribution of each appliance. SSA will enter into S&L programme implementation after other countries/regions of the world such as EU have been in practise for over forty years. This implies that SSA will be able to benefit immensely from the experiences gained and tools that have been used successfully in other countries. It would therefore be beneficial to implement S&L programmes for appliances/equipment in which labels and methods of measuring energy performance have been developed and are now matured. In doing so, Sub Saharan Africa will capitalize on already existing labels as well as already existing testing and certification centres.

Appliances/equipment to be included should be those with adequate market penetration levels implying high ownership levels. However, it will be important that the appliances in consideration at any implementation stage be common across the different S&L regions. This is calling for harmonisation of the S&L implementation process across the different regions. If this is not done, there will unfortunately be movement of inefficient appliances/equipment into the regions depending on whether regulation exists or not.

The following appliances are recommended for consideration for S&L programmes in SSA:

Lighting

Lighting products entering SSA market are either grid connected or non-grid connected lighting products. There have also been a number of initiatives for ‘lighting Africa’ that has resulted in high penetration of lighting products in SSA markets. It has been reported that sales of solar lanterns designed for low income households and micro-businesses grew by more than 300% in SSA between the period 2008 and 2012 [19] [20]. This indicates high market penetration rates for lighting products in SSA markets.

Refrigerators

The ownership of refrigerators in SSA countries is expected to grow slowly in the coming years and is projected that in 2030 half of the households will own a refrigerator [21]. Whilst this does not indicate high overall market penetration levels, it will be beneficial to include refrigerators for S&L programme in SSA for the following reasons:

- Ownership of refrigerators in urban centres is expected to grow faster because of expected increased urbanisation rates in SSA. At present, electrified areas in SSA countries are mostly urban areas and it is in urban areas where electrical energy supply is immensely constrained.
- Refrigerators are one of the highly sought appliances for second hand markets [16]. The refrigerators are imported as grey product and there is an urgent need to regulate the importation of such goods to prevent dumping.

Television sets

There are 44, 204,000 TV households at present in Sub Saharan Africa out of a total of 844 513 000 households [22]. This is not a very significant number to start with, but as for the refrigerators, rapid urbanisation will see the ownership rise sharply as the market for electronic goods continues to rise [14]. Again here, the issue of second hand good market is valid and it would be an oversight not to consider Televisions sets in an S&L programme implementation.

Radios and Mobile phone chargers

Radio receivers are the leading media equipment in the world and ownership levels for the world are reported to be 70-80 % on average [23]. In West Africa radio ownership in Togo, Nigeria, Senegal and Ghana is between 87% and 91% [23]. In Kenya and Tanzania in East Africa the ownership levels ranges between 92% to 93% [23].This is also the scenario in Southern Africa countries of Angola, Mozambique, South Africa and Zimbabwe where radio ownership is between 56% and 90% [23]. Needless to say, that this indicates high ownership levels across the board.

The high ownership levels are partly driven by the fact that radios can easily be powered by battery cells and therefore the ownership levels are not affected by lack of high electrification rates. But it is also true that because radios are well priced, most households can afford one. With the expected increase in electrification levels, and because of the affordability of radios more and more households are expected to switch to electricity powered radios.

Access to and use of mobile phones has increased rapidly in Sub Saharan Africa and in 2009 it was reported that 60% of the population in SSA had mobile phones [24]. In 2012, the number of mobile subscribers in SSA rose to 311 562 800 people out of a population of 844 513 902 [22]. Projected figures indicate that there will be 700 million connections in 2016 accounting for 75% of the population [25]. These numbers indicate very high ownership levels. All mobile phones require electrical battery chargers which normally consume low electrical power. The problem here is when mobile phone chargers are left on for considerable amount of time between charging events. This leads to standby power losses which can accumulate to relatively sizeable load if not attended to.

Consideration into standby power regulation for radios, televisions and mobile phone chargers should therefore be considered in the implementation of S&L programmes in SSA.

Harmonisation of Labels & Measurement Methods for Appliance Energy Performance

Harmonisation of labels and measurement methods already developed elsewhere will leapfrog the process of designing and implementing S&L programmes in SSA [7]. The labels and measurement methods and determination of minimum energy performance standards should however be tailored to the existing local conditions.

Institutional Capacity for Testing, Enforcement and Evaluation

This is another great challenge for the implementation of S&L programmes in SSA. Here is where international assistance and cooperation must be greatly tapped in [1]. Most of the appliances/equipment would be imported into the regions. The enforcement of S&L programmes will hinge mostly on import regulation at the ports of entry. The success will depend mostly on collaboration of exporting and importing countries as well as retailers.

Testing can be done through agreements with international testing laboratories. This is costly but harmonisation is the key in reducing costs especially when common appliances that use the same test methods are considered for S&L across the regions. Programme evaluation can also be done through the contracting programme experts obtained through the assistance of international organisation such as United Nations Development Programme (UNDP), Global Environmental Facility (GEF), and Collaborative Libelling and Appliance Standards Program (CLAS) SP to mention a few [1]. The implementation agencies can also be started by international consultancies working with regional local personnel for the purpose of capacity building.

Consumer Awareness Programmes

In Sub-Saharan Africa where appliance/equipment purchase is mainly driven by functionality and affordability (price), earnest efforts should be put into Consumer awareness programs. This is important in influencing the consumer appliance/equipment purchase and use behaviour which is paramount to the success of S&L programme. Careful tailored incentives could be introduced accelerate the purchase of energy efficient appliances/equipment. Mobile phones and radios coupled with advancement in technology could be the most practical and cost effective ways to disseminate energy efficient information to dispersed populations and households in SSA countries. Energy awareness campaigns can also be conducted through these two mediums of communication.

Conclusion

In the 40 years of implementation of S&L programmes in the world, the programmes have been initiated in only 4 countries and one economic region in Sub Saharan Africa. S&L have been initiated in Ghana, South Africa, Nigeria, Kenya and ECOWAS. The barriers to the uptake of S&L programmes in SSA countries have been articulated to be: The associated costs of design and implementing the programs, the non-existence of a favourable market and positive regulatory environment for S&L programmes.

The paper advocates that the present time is appropriate for SSA countries to embark on S&L programme design and implementation. The appropriateness of the time is substantiated by the expected increase in electrification rates in SSA which will in turn result in increase of ownership of appliances/equipment. The increase in appliance ownership levels will also be brought about by the fact that a substantial number of SSA countries will attain middle income status therefore raising household appliance/equipment purchasing power. The enactment and implementation of Energy efficient/environmental regulations in countries who are trading partners of SSA is another indicator for the appropriateness of the present time. Regulations such as ErP and the WEEE are the most significant because they directly affect the goods entering SSA. Sub Saharan Africa cannot afford to continue to be a dumping ground of non-compliant goods.

In the design and implementation of S&L programmes the following are recommended: An immediate response to by AU organs on mainstreaming of S&L programs in Africa. The existence of economic regions and regional power pools in SSA is an advantage in the formulation of S&L programmes which could be regional based to capitalize in economies of scale in terms of program costs and market sizes. Appliances/equipment considered for different stages of implementation should be common to all regions to benefit on harmonisation of test methods and labels. The appliances put forward for initial S&L programmes consideration are: lighting products grid and non-grid, refrigerators, television sets, radio and mobile phone chargers. The appliance/equipment market in most SSA countries is made up of imported goods. Market analysis and consumer analysis should be the analyses of choice due to data constraints. Finally consumer awareness and education as an important programme component in SSA S&L programme implementation is highlighted. The paper suggests the use of mobile phones and radios as media of communication in awareness and education programmes.

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Building Capacity for Better Enforcement of EU Eco-design and Energy Labelling in an EU Accession Country – Turkey Case Study

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Abstract

Based on the Customs Union obligations as well as accession efforts, Turkey is in the process of transposing and implementing EU Eco-design and Energy Labelling Directives as well as many other pieces of EU product legislation. Even though Turkey is the largest manufacturing base in Europe and the second largest in the world, Turkey still needs capacity building for better enforcement of the above mentioned legislation including for the market surveillance authority and upgrading energy efficiency testing facilities.

The Turkish Ministry of Energy and Natural Resources chose the United Nations Development Programme (UNDP), as the Implementing Agency, with financial support from the Global Environment Facility (GEF) and launched the UNDP/GEF Market Transformation of Energy Efficient Appliances in Turkey Project, MTEEA (2010 to 2014) [1]. The project aims to transform the market towards more efficient appliances through a set of activities, primarily focusing on:

1. Establishment of a Market Monitoring System to monitor, manage and control Green House Gas (GHG) emissions caused by household appliances.
2. Capacity building for Turkish Governmental institutions for accelerated transposition, implementation and better enforcement of EU Energy Labelling and Eco-design Regulations.
3. Revised and upgraded Proactive Market Surveillance Programme, including a strengthening of the institutional capacity to test appliances in Turkey.

The project also includes provisions for raising public awareness for more efficient appliances, development of financial support mechanisms and training of sales staff to help sell the benefits to consumers of energy efficient household appliances.

This paper describes activities undertaken to build the necessary capacity and presents the results which have been achieved so far as well as what further steps should be taken in the future.

Introduction

The rapid diffusion of globalization, beginning in the 1990s, changed the consumption habits of communities across the world, creating rapid consumption of energy resources, thereby increasing concerns about global climate change. This trend pushed most governments to take action for more rational and efficient use of resources without imposing barriers to trade. As a result the issue of resource efficiency became one of the most important items on the world agenda.

Under the Customs Union between Turkey and the EU, a collective transposition movement began following it’s publication in 1995. Most of the regulations transposed focused on product safety, with the exception of the energy labelling regulations for household appliances, household refrigerating equipment 96/57/EC, fluorescent ballasts 2000/55/EC, and New Hot Water Boilers (NHWB) 92/42/EC.

However, the first framework directive 2005/32/EC for setting eco-design requirements for Energy using Products (EuP) as well as Implementing Measures thereunder for different product groups provided for minimum requirements for energy efficiency and prohibited the selling of EuPs not meeting these requirements. Later in 2009, the scope of the framework eco-design directive was extended to cover all products which directly or indirectly affect energy consumption and recast under 2009/125/EC for setting eco-design requirements for Energy related Products (ErP). The recast of the framework directive meant that products consuming vital resources such as gas and water, construction materials and even detergents which affects consumption of resources, were eligible to be included. Therefore it has been witnessed that resource efficiency based legislation takes equal prominence to that of product safety.

In the following sections, the details will be presented of how the transposition of the EU eco-design legislation as well as the recast of the EU Energy Labelling legislation was accelerated and how capacity for better enforcement of this legislation was built into Turkish governmental institutions.

Market Transformation of Energy Efficient Appliances in Turkey Project

Just after the transposition of Directive 2009/125/EC in Turkey in October 2010, the DG for Renewable Energy under the Ministry of Energy and Natural Resources and UNDP launched the GEF supported project “Market Transformation of Energy Efficient Appliances in Turkey” as a market transformation programme towards more efficient appliances focusing on refrigerating equipment, wet products, electric ovens, air conditioners and televisions which is also supported by project partners from both industry and government.

Table 1 below presents the project partners which support the MTEEA Project:

Table 1 – Shows the MTEEA Project Partners

Ministry of Energy and Natural Resources, DG for Renewable Energy	Executing Agency for MTEEA Project and responsible for establishing general energy efficiency policies in all sectors in Turkey
Ministry of Science Industry and Technology	Responsible for transposition and enforcement in Turkey of many parts of *Acquis Communautaire* including Eco-design and Energy Labeling
Turkish White Goods Manufacturers’ Association (TURKBESD)	An industrial NGO representing white goods industry in Turkey
Arçelik A.Ş.	Worldwide reputable Turkish appliance manufacturer
Global Environment Facility (GEF)	International fund supporting climate change mitigation and adaptation projects in developing countries
United Nations Development Programme (UNDP)	Global network of the United Nations established in 1966 and operating in 177 countries in the world supporting national and global development efforts for better life quality for communities

The objective of the MTEEA Project is to reduce the household electricity consumption and the associated GHG emissions of Turkey by accelerating the market transformation of less energy consuming appliances. The project is being implemented to achieve the following outcomes:

- strengthening local institutional capacity to develop, adopt and implement effective appliance EE policies;
- developing and implementing a structured conformity assessment and enforcement program for appliance energy performance labels and standards;
- increasing consumer and the supply chain awareness and capacity to purchase and deliver energy efficient appliances in the Turkish market; and
- analyzing and reporting the results of the project for further learning, adaptive management and, as applicable, replication in other countries.

Improvement of the Regulatory Framework and Capacity Building Activities

Legal Framework:

In the early implementation phases, the MTEEA Project proceeded with the acceleration of the transposition of Implementing Measures under the Eco-design Framework Directive 2009/125/EC and Delegated Acts under the Energy Labelling Framework Directive 2010/30/EU for products covered by the scope of the Project. In this context, MTEEA supported the Turkish Ministry of Science Industry and Technology (MoSIT) in transposing the following Implementing Measures and Delegated Acts [2].

Table 2. Shows the Implementation of EU eco-design and energy labelling regulations into Turkish Law

Regulations	Published in
2009/125/EC Framework Eco-design Directive	**October 2010**
• 642/2009 – Televisions	September 2011
• 643/2009 – Refrigerating appliances	September 2011
• 1015/2010 – Washing Machines	September 2011
• 1016/2010 – Dishwashers	September 2011
• 206/2012 – Air Conditioners	FINAL DRAFT
• 1275/2008 – Standby/Off	August 2011
• 107/2009 – Simple Set Top Boxes	August 2011
• 244/2009 – Non-directional household lamps	August 2011
• 245/2009 – Tertiary lighting	August 2011
• 278/2009 – External Power Supplies	August 2011
• 641/2009 – Circulators	September 2011
2010/30/EU Framework Labelling Directive(*)	**December 2011**
• 2002/40/EC – Electric Ovens	February 2003
• 1060/2010 – Refrigerators	June 2012
• 1061/2010 – Washing Machines	June 2012
• 1059/2010 – Dishwashers	June 2012
• 1062/2010 – TV	June 2012
• 626/2011 – Air conditioners	FINAL DRAFT
• 392/2012 – Tumble Driers	FINAL DRAFT

(*) Former labelling regulations were repealed as new version labelling regulations are put into force.
(**) Those transposed under the MTEEA Project are shaded in grey.

Market Monitoring System

In parallel to the publication of the above listed regulations in Turkey, a Market Monitoring Database was developed within the DG for Renewable Energy under the Ministry of Energy and Natural Resources to summarize the annual sales of appliances by energy efficiency classes as well as energy consumption figures and associated GHG emissions caused by appliances. This database will, if updated every year, enable the DG for Renewable Energy to better administer energy efficiency policies by monitoring the energy consumption and GHG emission figures and the Ministry of Science Industry and Technology to better design their Market Surveillance Plans based on the sales figures of appliances by energy efficiency classes.

The database can be extended to include new product groups as new implementing measures and labeling regulations are introduced. To enable effective use of the database, the Measurement, Evaluation, Monitoring and Audit Department staff of the DG for Renewable Energy was trained in April 2012 [3].

Market Surveillance Infrastructure

Although publication of the regulations is an important step, it should be backed by effective enforcement complete with trained market inspectors, a structured market surveillance plan and testing facilities. For this reason, 300 MoSIT headquarter staff and market inspectors have been trained by an international expert from the Energy Saving Trust (EST), UK, on the implementation of EU eco-design and energy labeling directives and implementing measures and delegated acts respectively. In addition, for further capacity building purposes, a market surveillance strategy was implemented. The proactive plans of MoSIT have been enhanced to cover checking compliance of products with these pieces of legislation, and the headquarters staff of MoSIT was provided with training on market surveillance programme management by the National Measurement Office (NMO), the market surveillance authority in the UK for eco-design and energy labelling. This is a key result of the MTEEA project – for the first time, MoSIT benefited from a capacity building programme for eco-design and energy labelling regulations as the two previous Twinning Projects implemented by MoSIT with EU Member States in 2004 and 2006 mostly focused on product safety directives.

Training

MoSIT is the market surveillance authority in Turkey for products covered by a number of European Directives on safety and performance including LVD, EMC, Machinery, Lifts, NHWB, Gas Appliances, Civil Explosives as well as eco-design and energy labelling of products. Before the MTEEA project, all the training of market inspectors had focused on product safety and not eco-design and the energy labelling regulations. Consequently, MoSIT recognized the MTEEA project as a valuable opportunity to fill their capacity gap. Considering these training needs, the MTEEA management devised a training programme on eco-design and energy labeling regulations to cover both HQ staff (training of trainers) and market inspectors, totaling 300 people. MoSIT also needed market surveillance programme management training for delivery of the Proactive Market Surveillance Plan (PMSP) developed under MTEEA (as detailed below) and for the continued delivery of market surveillance after 2014 [4, 5]. Securing the Ministry's co-operation past 2014 is a major result for the MTEEA Project.

In collaboration with the NMO, a two-stage training programme was designed and implemented for MoSIT HQ staff:

- **Stage I:** Environmental Impact, Development of Market Surveillance Programmes, Enforcement Actions, Monitoring and Measuring Achievement of the Market Surveillance Programme
- **Stage II:** Follow-up of Progress of MoSIT's Market Surveillance Programme

Results

With this training, MoSIT were able to manage the PMSP in co-operation with the MTEEA Project Management Unit and to better restructure their market surveillance organization using the outcomes of the training.

Proactive Market Surveillance Plan

Previously, MoSIT's annual market surveillance programmes focused on product safety. Previous energy labelling surveillance focused only on the presence of labels, with only household lamps undergoing any performance and verification testing. The MTEEA project ensured, with the help of an International Consultant, that a comprehensive product testing programme was developed – to be implemented in two stages in two years (2013-2014) – covering all products included within the scope of the Project.

STAGE I (2013): *Establishing the baseline*. This first stage of the product testing programme is intended to provide an overall picture of the level of compliance of the marketplace for MoSIT. This seeks to help better design their future market surveillance programmes to decide on hot spots, product groups, country of origin, manufacturers, brands and models to be focus on. The testing programme is designed to cover as many brands and models as possible under the budgetary limits of the MTEEA Project.

STAGE II (2014): *Measuring the change in the level of compliance*. This second stage of the testing programme is intended to enable the MTEEA Project Management and MoSIT to measure to what extent the MTEEA Project activities are successful in increasing the level of compliance of the marketplace.

Results

This PMSP is considered another key output of MTEEA Project. For the first time, a market screening programme has been prepared and will be delivered by MoSIT to check compliance with EU eco-design and energy labelling regulations.

Enhancing Testing Capacity

Success of a market surveillance programme is dependent on equipped and competent training facilities and personnel. Currently, the Turkish Standards Institute (TSE) is the testing body authorized by MoSIT in Turkey for testing of products subject to product regulations under the responsibility of MoSIT. As far as eco-design and energy labelling regulations are concerned, however, TSE has limited testing capacity for some products (refrigeration, electric ovens, TVs) and no testing capacity for some other products (laundry and dishwashing, air conditioners). Therefore, a capacity building programme was initiated by the MTEEA Project to undertake a laboratory inventory within Turkey, to devise a laboratory investment programme and to train laboratory staff [6].

Laboratory Inventory

The objective was to establish an inventory of testing facilities in Turkey (both private and public) for testing of products against eco-design and energy labeling regulations. Table 3 displays the results of this exercise:

Table 3. Shows the Capacities and Gaps in Testing Facilities in Turkey

Product	Can these be currently tested in Turkey?
Domestic fridge, freezers and similar	Yes at TSE
Domestic washing machines	Only in manufacturer-owned facilities
Domestic dishwashers	Only in manufacturer-owned facilities
Domestic tumble driers	Only in manufacturer-owned facilities
Electric ovens	Yes at TSE (limited)
Air conditioners	Only in manufacturer-owned facilities
TVs	Yes at TSE (limited)

As a result of this inventory, a 4-option strategic proposal was offered to MoSIT for upgrading the testing facilities in Turkey:

Table 4. Displays the Strategic Options for Upgrading Testing Facilities in Turkey

Option	Advantage	Disadvantage
Option 1: Test all (future) Energy Labelling and Eco-design products in Turkey at a University or other independent site.	Builds skill base and product knowledge in research capable centres within Turkey.	Very high (€millions) investment cost. High training and staff familiarisation cost.

Option 2: Test all (future) Energy Labelling and Eco-design products in Turkey at TSE.	Uses and builds testing expertise within Turkey's current testing centre.	High (€million+) investment cost (though some/all investment could possibly be made by TSE).
Option 3: Test all (future) Energy Labelling and Eco-design products in Turkey at TSE (where TSE has facilities) and at manufacturers' laboratories in Turkey using TSE staff.	Uses and builds testing expertise within Turkey's current testing centre, minimises investment costs.	Access to manufacturers' laboratories may be restricted and require advanced booking.
Option 4: Test those products at TSE where they already have facilities. Test all other products at a suitably qualified laboratory elsewhere in the EU.	No investment costs, access to a competitive market for the supply of testing services.	Minor. Need to set up suitable administrative procedure. Some difficulties associated with arranging the witnessing of testing. Note: several EU Member States use this option.

Having considered these four strategic options, MoSIT decided to begin by adopting a version of Option 4, with the addition of investing in air conditioner test facilities, thereafter to continue to invest in further test facilities, in a phased programme over a further 2 years, to arrive at Option 2. Upon this decision the MTEEA project proceeded with developing a Laboratory Investment Plan for TSE.

Laboratory Investment Plan

The plan covered investment for testing of laundry and dishwashing products and air conditioners to EU eco-design and energy labelling requirements and included provision of training of testing staff of TSE. The plan was also shared with TURKBESD, and a very valuable collaboration was established to finalize the list of equipment and costs. Turkish appliance manufacturers have excellent testing facilities and expertise regarding eco-design and energy labelling testing of products. As a result of discussions with MoSIT and TSE, the Turkish government decided to develop air conditioner testing facilities at TSE. TSE delivered their commitment to make the necessary investment for developing testing facilities for energy efficiency testing of wet products and air conditioners in 2013 and to be ready for testing in 2014. This will be an important step in Turkey, facilitated by the MTEEA Project, to remove the gap in testing facilities which has been under discussion for nearly 10 years. For the product groups which can already be tested by TSE (i.e. cold products, electric ovens, TVs) the list of testing equipment already available within TSE were also reviewed by working groups for each product group, where TSE, TURKBESD members and MoSIT are represented, to identify missing or outdated testing equipment, improper setup (if any) and provide TSE with full testing capacity by bringing their laboratories proper operating condition.

Training of Testing Staff

As part of the Laboratory Investment Plan, analysis was carried out with TSE with the help of an International Consultant to identify the training needs of TSE testing staff. Considering the results of this, a training programme was developed for TSE testing staff including mutual laboratory visits, theoretical standard training, practical training at manufacturers' laboratories and training at EU laboratories accredited to EN 17025. This training programme has already been initiated and is expected to be completed in 2013 [7].

Other Activities - Consumer Awareness Survey, Training Of Sales Staff, Public Awareness Raising Campaigns

Consumer Awareness Survey

Intended market transformation can be achieved only if consumer awareness is sufficiently raised. Therefore, another objective of the MTEEA project is to raise awareness of consumers regarding efficiency of appliances.

In line with this objective, as a first step, a consumer survey was designed and implemented to identify a baseline for the level of awareness of consumers about these issues and to help design the awareness raising campaign. The Consumer Survey Report [8] published in June 2012, identified the following trends:

- Females are more aware than males about energy efficiency in both rural and urban settlements;
- About 56% of the Turkish population claim awareness of energy labeling;
- The level of awareness about climate change is relatively high but the impacts by householders on climate change by, for example, purchasing in-efficient home appliances could not be positively correlated;
- Financial support mechanisms are necessary to accelerate the phase-out of old and inefficient appliances.

This consumer survey will be repeated after the public awareness raising campaign to identify to what extent the level of awareness has been increased as a result of the activities under the MTEEA Project.

A project website has also been designed and launched to promote the project objectives (Figure 1).

Figure 1. A screen shot from the MTEEA Project website [1]

Training of Sales Staff on Energy Labelling and Sales Techniques

The consumer awareness survey noted that most of the Turkish people buy appliances after they physically see and check them at stores. The survey found that only 2-2.5% of them were informed of the energy efficiency aspects by salespersons in-store. This led the MTEEA project to design and deliver a training programme for sales staff covering the responsibilities of suppliers and dealers under the energy labelling regulations, about the information contained on the energy label and about sales techniques to highlight the energy efficiency properties of appliances. This training programme has been delivered in two phases:

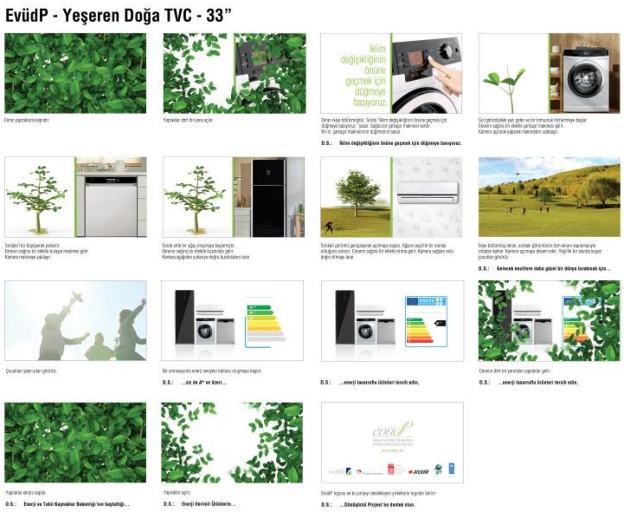
PHASE I: This training targeted the salespersons of TURKBESD members as well as department stores who directly communicate with customers. It was delivered to a pilot group of 40 salespersons attended from stores of Arçelik and other TURKBESD members such as BSH, Vestel and Indesit as well as department stores like Metro, Real and Teknosa.

PHASE II: This training targeted 30 staff working in marketing and sales departments of TURKBESD members and prepared training documents and delivered sales training techniques to store salespersons to increase the profile of energy efficiency aspects in their training curricula.

Training attendees benefited from an increased understanding of the contents of the energy label. Turkey has some 40,000 to 50,000 retail sales staff; unfortunately, given the resource constraints of the programme, it was not possible to train more staff.

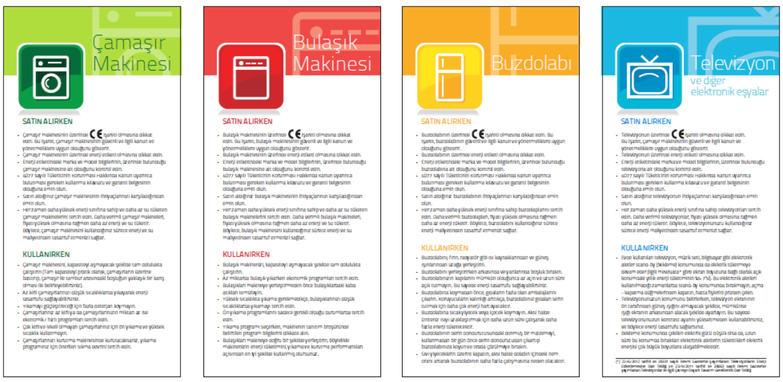
Public Awareness Raising Campaign:

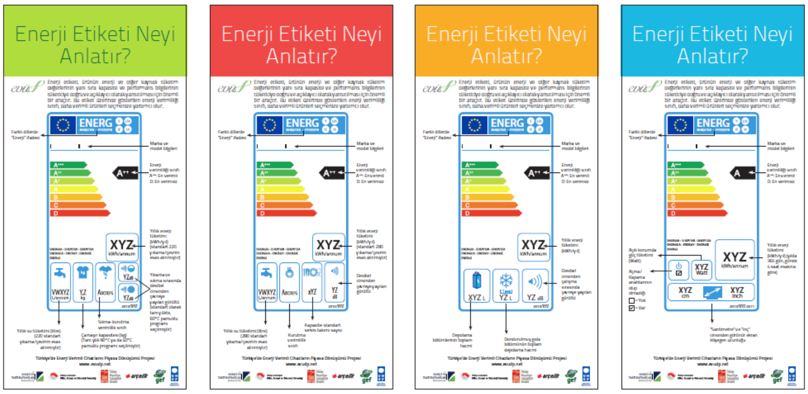
Based on the results of the consumer awareness survey, a set of promotional materials including TV and radio spots, newspaper advertisements, cinema spots and internet advertisements were produced, broadcasted and published in national media, including 6 prominent TV channels and the 4 highest circulated national newspapers, and on the internet (Figure 2). In addition, energy label flyers were also printed to be disseminated in appliance shops and department stores to inform consumers about the symbols and information presented on energy labels and to correctly guide them when buying and using appliances.



TV & Cinema Spot

Newspaper advertisement





Label Flyers

Figure 2. Examples of Promotional materials prepared under the MTEEA project

Key Results

- The creation of the country's first Market Monitoring System, which estimates that the aggregate reduction in electricity consumption as a result of the MTEEA project's activities is 5.8 TWh by 2014 and nearly 30 TWh by 2020.
- The adoption of 8 eco-design and energy labelling regulations which have then gone on to be published into Turkish Law, with a further 3 regulations drafted remaining as yet un-published.
- The training of 300 MoSIT headquarter staff and market inspectors on energy labelling and eco-design, with MoSIT headquarter staff also benefiting from market surveillance programme management training.
- The establishment for the first time in Turkey of a market surveillance programme to check compliance of products with energy labelling and eco-design regulations.
- The creation of an inventory of laboratory product testing capacities, a laboratory investment plan to close the gaps and training of laboratory staff and the delivery of the commitment by Turkish Standards Institute to implement this investment plan.
- The delivery of a consumer research survey to establish a baseline of understanding of the Turkish population towards energy efficiency.
- The training of a total of 70 sales staff on the contents of the energy label and how to profile energy efficiency in selling products.
- The delivery of a consumer awareness raising campaign across national media.

Conclusions

The MTEEA Project has delivered many new achievements in Turkey as listed above under the "Key Results". However, as it is a single project, it is only a first step. Therefore, considering that the project will be implemented during a period of 4 years, it is very important to have the results and achievements obtained during the project implementation owned and sustained by all stakeholders. These include government, manufacturers and suppliers, consumers and media institutions. The efforts will be useful in order to utilize national resources more rationally and efficiently and to leave a better world to following generations. This accomplishment will be the most relevant achievement of the MTEEA Project.

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Timely replacement of notebooks considering energy consumption and global warming potential

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Abstract

The production of notebooks induces significant environmental impacts. However, these impacts are seldom considered by consumers in their purchasing decisions. The crucial question addressed in this paper is when the global warming potential associated with the production, distribution and disposal of a new notebook can compensate as a result of energy efficiency gains in the use-phase of the new notebook. This paper shows that the production, with about 56% of the global warming potential (GWP) of a notebook has a significantly higher impact than the use phase. Moreover, the GWP of the production of a notebook is so high, that it cannot be compensated in realistic time-periods by energy efficiency gains of new products. The paper recommends decision makers to give attention to the extension of the lifetime of notebooks, for example through hardware upgrading, modular and repair-friendly product design, standardisation of components, minimum warranty periods, and availability of spare parts, while defining mandatory product policy for Information and Communications Technology (ICT).

Introduction

Recent life cycle assessments show that the raw materials and manufacturing phase of many ICT products have a proportionally increasing environmental impact as compared to the use phase. It is assumed that the reason for this lies in the energy efficiency gains during the use phase, especially those of mobile appliances, combined with the extremely short product life cycles of most ICT. The high rate of innovation in the sector and the falling prices for new units are causing the actual lifetime of ICT products to become ever shorter. There is empirical evidence that notebooks often have a useful lifetime of less than 3 years [1], [2].

To gain a full picture of the environmental impacts attributable to notebooks, it would be essential to include the material consumption and appropriation of environmental carrying capacity arising in both the upstream and downstream phases. Such a perspective would give policy-makers, public buyers and private consumers more certainty regarding the decision between the extension of lifetime of an existing notebook and the purchase of a new one. Furthermore, such a life cycle analysis makes it possible to determine with greater accuracy and predictive certainty when and under which conditions the replacement of an old device with a new one would be reasonable from an environmental perspective.

Against this background, the German Federal Environment Agency (UBA) commissioned the Öko-Institut e.V. and the Fraunhofer IZM with a study [3] to address the following questions:

(1) What are the contributions of the different life cycle phases to the overall greenhouse gas emissions (GWP) of a notebook?

(2) When is the optimum time to replace an old notebook by a new model in environmental terms?

Methodology

The questions mentioned above were examined comparatively by using various data sources:

(1) EuP Lot 3[1] – PCs (desktops and laptops) and Computer Monitors => Scenario 1

(2) Database EcoInvent 2.2[2] => Scenario 2

(3) UFOPLAN 2009 environmental research programme of the UBA => Scenario 3 (End-of-Life Management = Business-As-Usual)

(4) UFOPLAN 2009 environmental research programme of the UBA => Scenario 4 (End-of-Life Management = Best Practice)

The UFOPLAN 2009 project[3] generated a new dataset for the liquid crystal display (LCD) modules and for 8 GB memory ICs which are typically used in a RAM module of an average notebook [4]. These data are publicly accessible in the ProBas database at www.probas.uba.de and have been used for the modelling of the production phase.

The following table describes the detailed modelling scenarios for the individual life cycle phases:

Table 1: Overview of data sources and assumptions for the scenarios studied

<table>
<tr><th rowspan="2">Scenario</th><th colspan="5">Calculation of</th></tr>
<tr><th>Production phase</th><th>Distribution phase [km]</th><th>Shopping trip</th><th>Use phase</th><th>End-of-life phase</th></tr>
<tr><td>1</td><td colspan="2">Following EuP Lot 3</td><td rowspan="4">Assumption: 10 km round trip by car</td><td rowspan="4">In accordance with the utilisation profile of Energy Star Version 5.0</td><td>Following EuP Lot 3</td></tr>
<tr><td>2</td><td>On basis of data from EcoInvent 2.2</td><td rowspan="3">Assumptions:
1) Production sites – airport; truck: 500
2) Shanghai – Warsaw; flight: 8000
3) Distribution to retailers; truck: 1000</td><td>Business-as-usual</td></tr>
<tr><td>3</td><td rowspan="2">On basis of data from UFOPLAN 2009 (display module & ICs) + EcoInvent 2.2 (other components)[4]</td><td>Business-as-usual</td></tr>
<tr><td>4</td><td>Best practice</td></tr>
</table>

In the EuP Lot 3 study, a lifetime of 5.6 years is considered for laptops. As for the database such as EcoInvent and data from UFOPLAN, there is no assumption about lifetime. For our study, we assume a lifetime of 5 years to all scenarios in the basis analysis. A sensitivity analysis with a lifetime of 2.9 years will be conducted. The use phase in the scenarios 1 to 4 is assumed to be the same (they are based on the Energy Star 5.0 Specifications for Computers) as it enables a direct comparison between the results of the production phase in all the four scenarios.

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[1] EuP 2007; European Commission, DG TREN; Preparatory studies for Eco-Design Requirements of EuPs, Lot 3: Personal Computers (Desktops and Laptops) and Computer Monitors, Final Report (Task 1-8), IVF Industrial Research and Development Corporation, 2007

2 EcoInvent v2.2, 2010; EcoInvent Centre (Swiss Centre for Life cycle Inventories); http://www.ecoinvent.ch/

[3] The overall project was titled "*Resource conservation in the field of information and communication technologies (ICT)*" (funding code 3709 95 308), under which sub-project C, titled "*Establishing a data base for the evaluation of ecological effects of ICT products*" generated the dataset in question.

[4] Including consumption in production processes

Scenarios 3 and 4 only vary in terms of the end-of-life management. It is assumed that in scenario 4, the best-practice variant, precious metals such as Gold (Au), Silver (Ag) and Palladium (Pd) are recovered with greater efficiency than in the business-as-usual scenario 3. These efficiency improvements can be achieved mainly through optimised manual pre-treatment that largely avoids subsequent mechanical processing by shredding. The following table shows the recovery rates assumed in the scenarios 3 and 4:

Table 2: Estimated recovery rates used in this study

Precious metal	Business-as-usual (Scenario 3)	Best Practice (Scenario 4)
Ag	40%	87%
Au	40%	93%
Pd	40%	91%

The data sources used in the present study (Table 1) refer to different notebook configurations and technical specifications. However, the function of the different notebook variants is considered to be equivalent (Table 3).

Table 3: Notebook specifications in EuP Lot 3, EcoInvent 2.2 and UFOPLAN 2009

	EcoInvent 2.2	EuP Lot 3	UFOPLAN 2009
CPU	Pentium 3, 600 MHz	1.7 GHz	Pentium 3, 600MHz[5]
HDD	10 GB HDD	60 GB HDD	10 GB HDD[3]
Memory IC	128 MB RAM	512 MB RAM	8 GB
Display size	12.1″	15″	15.4″
Weight with (without) packaging	3.15 kg (2.17 kg)	3.7 kg (2.8 kg)	3.3 kg (2.4 kg)[6]
Ref. year	2005	2005	2000-2010

It should be emphasized that the goal of the study is not to produce a comparative LCA of different notebooks, but rather to determine the best point in time in environmental terms to replace a notebook, on the basis of a range of data sources. The configuration of the notebook in the scenarios 3 and 4 is therefore a fictitious assumption – it does, however, correspond to the configuration of a *typical* notebook.

The procedure adopted for this LCA study follows ISO 14040/44 (2006), but only examines one impact category, namely Global Warming Potential (GWP). This is purposeful because GWP correlates directly with energy consumption in both the use and the production phase. Due to poor data availability, it was not possible in the context of the present study to consider further impact categories such as acidification and eutrophication potential, photochemical oxidant formation and ecotoxicity.

The functional unit is defined as 1 notebook over its entire useful lifetime. The lifetime of all notebooks studied was taken to be 5 years.

Contribution of the different life cycle phases to the overall GHG-emissions of a notebook

The following Figure 1 illustrates the contribution of the different life cycle phases to the overall GWP of a notebook, calculated according to various data sources:

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[5] Taken from EcoInvent 2.2

[6] The weight of the display and memory ICs (from UFOPLAN 2009) and the weight of other components (from EcoInvent 2.2) were added.

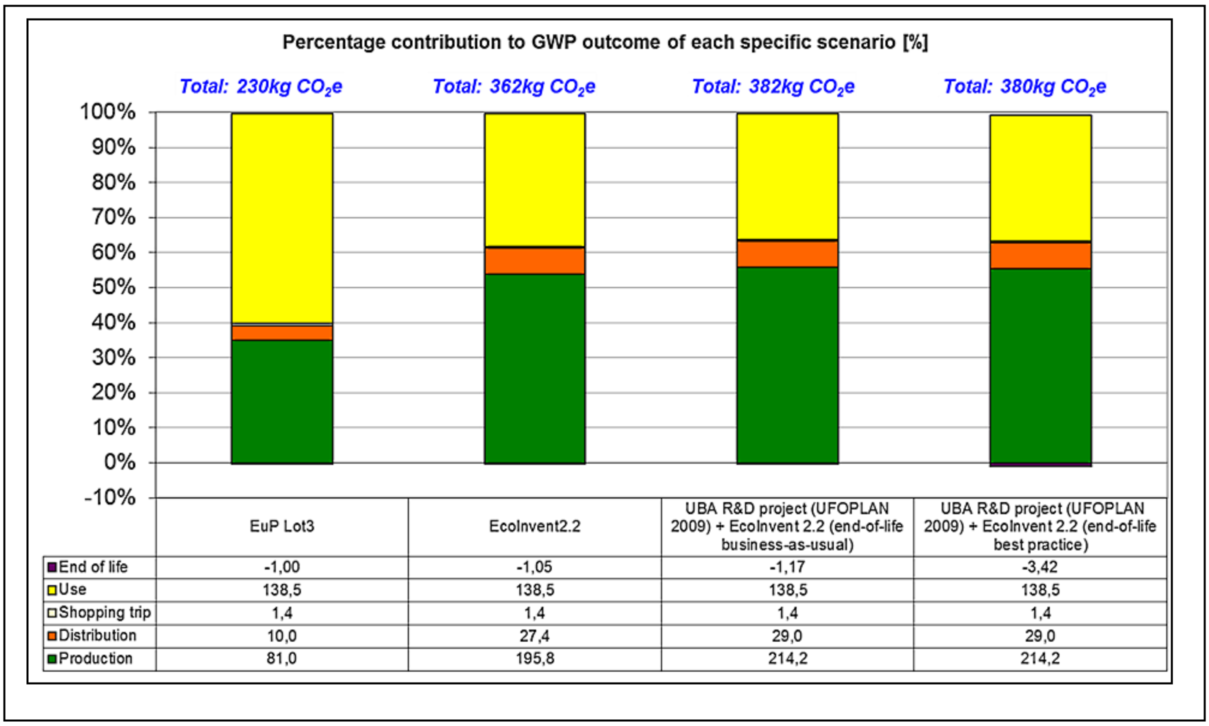

Figure 1: GWP emissions (in kg CO_2e/notebook and percentage) outcome for all scenarios studied, differentiated according to life cycle phase

Overall, the EuP Lot 3 scenario (Scenario 1) results in 230 kg CO_2e over the entire life cycle of a notebook. The greatest proportion of GWP arises in the use phase with 60.2%, followed by the production phase with 35.2%. The EcoInvent 2.2 scenario (Scenario 2) results in the GWP of 362 kg CO_2e over the entire life cycle of a notebook. The production accounts for the largest proportion of GWP emissions with 54%, followed by the use phase with 38.2%.

Scenario 3 (UFOPLAN 2009, Business-as-Usual End-of-Life Management) results in 382 kg CO_2e over the entire life cycle of a notebook. Production accounts for the largest proportion of GWP emissions with 56%, followed by the use phase with 36%. Scenario 4 (UFOPLAN 2009, Best Practice End-of-Life Management) results in 380 kg CO_2e over the entire life cycle of a notebook. Production accounts for the largest proportion of GWP emissions with 56%, followed by the use phase with 36.5%.

In the scenarios 3 and 4, new datasets for the display module and integrated circuits (memory chip) of an average notebook were used for modelling the production phase, as prepared under the UFOPLAN 2009. The resulting GWP values are listed in Table 4 together with the GWP values of the other components from EcoInvent 2.2, with 1 notebook as reference unit. The production and transport of the display module account for about 18% of the GWP emissions of the entire production of a notebook. The production of the memory chip accounts for about 3.5% [4].

Table 4: Specific outcomes for the display module and memory ICs from the UFOPLAN 2009 (kg CO_2e/notebook) [4]

Outcomes	GWP [kg CO_2e/NB]	Proportion
Display module: Production [4]	35.1	16.4%
Display module: Transport	3.4	1.6%
Memory ICs (8GB): Fabrication [4]	7.6	3.5%
Memory ICs (8GB): Transport (silicon wafer – front-end process – back-end process – notebook assembly)	0.03	0.01%
Other components (EcoInvent 2.2)	168	78.5%
Total	214	100%

In case of the memory chip, with around 66% the front-end process accounts for the largest contribution to the GWP emissions of the memory chip fabrication, followed by the back-end process with 20% and the silicon wafer production with 14% [4].

Comparing the four scenarios, it can be seen that the GWP of scenario 1 (EuP Lot 3) is the lowest. Furthermore, in scenario 1 the use phase is dominant, while in the other three scenarios the production phase makes the greatest contribution to the overall outcome.

The reason for the minor difference in the distribution phase of scenarios 2, 3 and 4 is that the notebooks studied have different weights (Table 3) and the environmental impact resulting from transport is calculated according to the weight of the freight (with the same assumptions regarding kilometres travelled, truck size and truck capacity utilisation).

The results for the use phase (assuming a useful lifetime of 5 years) and the shopping trip are the same in all scenarios. Due to their small proportion, the shares of the shopping trip and the end-of-life phase are not visible in Figure 1. Together they account for less than 1 per cent of the total GWP emissions.

Calculations of amortisation periods based on the energy efficiency improvement in the use phase

In order to calculate amortisation periods (in years) it was assumed that the new notebook is more energy-efficient during the use phase than the old one. This assumption is based on the fact that computers have the continuous improvement of energy efficiency in the use phase along with the technological progress. To model different scenarios for different levels of energy efficiency improvement of new notebooks compared to old ones, energy efficiency improvement classes were formed with intervals of 10 per cent. A 10% interval is an assumption to show the development of energy consumption under a continuous improvement of energy efficiency. This means that the new notebooks are improved by 10% energy efficiency increments in the use phase (compared to the baseline scenarios 1 to 4), until an energy efficiency improvement of 50% is reached. A further calculation is performed for an increase by 70%. In other words, the GWP outcomes of the new notebooks in the use phase always develop in step with the energy efficiency improvements. This results in different GWP outcomes over the entire life cycle of the new notebook, whereby the GWP values of production, distribution (incl. shopping trip) and disposal always remain the same.

The saving potential in the use phase that results from energy efficiency improvement compared to the old device (base scenarios) can be calculated as follows:

$GWP_{Saving\ potential}$ = GWP_{Use} [kg CO_2e/year/notebook] * x [%] whereby

GWP_{Use} (kg CO_2e/year/notebook) represents the annual greenhouse gas emissions of the old notebook in the use phase

x is the energy efficiency improvement (in %) of the new notebook.

The corresponding amortisation periods (years) can be calculated as follows: the GWP value of production, distribution (incl. shopping trip) and disposal is divided by the GWP values saved due to energy efficiency improvement (savings in use compared to the old notebook) of the new notebook.

It has to be noted that possible changes in the framework conditions were not taken into account, such as changes in the emission factor of the electricity mix that might arise from the substitution of an energy carrier, energy efficiency improvement of electricity supply, or changes in utilisation patterns over time. The analysis is therefore a static one.

Figure 2 gives an overview of the amortisation periods of all scenarios studied. As a general principle, the higher the energy efficiency improvement of the new notebook compared to the old one is, the shorter is the amortisation period.

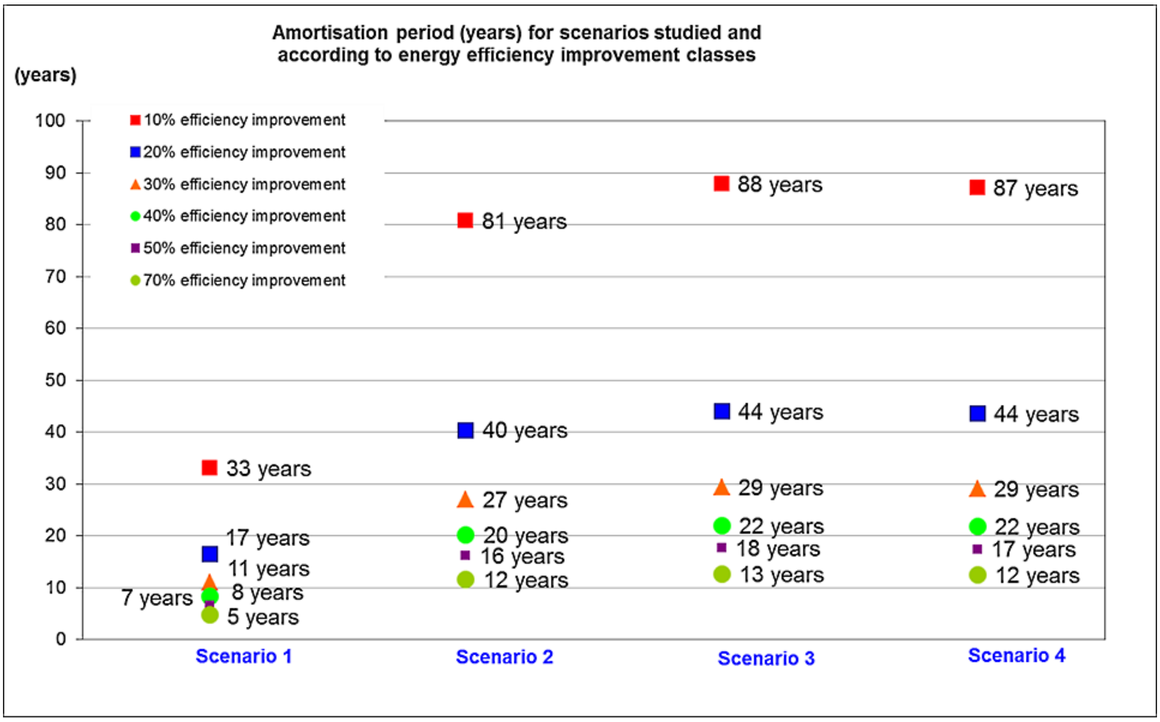

Figure 2: Overview of amortisation period as a function of energy efficiency improvement in the use phase, for all scenarios

As shown in Figure 2, if the new notebook is 10% more energy-efficient in use, the amortisation period for the replacement purchase is between 33 and 89 years (depending upon the data source). This means that the old notebook would have had to be used between 33 (scenario 1, EuP Lot 3) and 88 years (scenario 3, UFOPLAN 2009) to compensate the greenhouse gas emissions attributable to the production, distribution and disposal of the new notebook. If the energy efficiency of the new notebook increases by 70% compared to the old one, the amortisation period shortens between 5 (scenario 1, EuP Lot 3) and 13 years (scenario 3, UFOPLAN 2009), depending upon data source. The additional consideration of increased precious metal recovery has only a marginal impact on the overall outcome (cf. scenarios 3 and 4).

Sensitivity analysis

The principal input quantities for the calculation of GWP emissions are:

- the quantity of electricity consumed,
- the operational modes in the use phase and
- methodological uncertainties.

Inaccuracies attached to these quantities can therefore significantly influence the GWP outcome. This section examines systematically the influence of the input quantities upon GWP emissions. This is done by performing sensitivity analyses examining those parameters that involve uncertainties or which were based on estimations.

Sensitivity 1: Adjustment of electricity consumption values and of operational modes in the use phase according to EuP Lot 3

For the purposes of this sensitivity analysis, electricity consumption levels and the weighting of operational modes were taken from EuP Lot 3 (Table 5):

Table 5: Electricity consumption according to EuP Lot 3

Operational mode	According to EuP Lot3	Hours per year	Power absorbed (kW)	Electricity consumption (kWh/year)
TOff	36%	3153	0.0015	4.73
TSleep	34%	2995	0.003	8.99
TIdle	30%	2613	0.032	83.62
Total	100%	8761	–	97.33

Comparing this electricity consumption with that of the baseline scenarios 1 to 4, it is seen that the electricity consumption and GWP values in the use phase increase by 110%. The increased GWP values in the use phase cause the overall outcome to change by 40% to 66% (Table 6).

Table 6: Results of sensitivity analysis 1 compared to the base analyses of all scenarios (Sc) examined

Total GWP of a notebook (kg CO_2e/notebook)	EuP Lot3 (Sc 1)	EcoInvent 2.2 (Sc 2)	UFO-PLAN 2009 (Sc 3)	UFO-PLAN 2009 (Sc 4)
Base analysis	230	362	382	380
Sensitivity analysis 1	383	515	535	535
Deviation from base analysis	+66%	+42%	+40%	+41%

Consequently, due to the higher electricity consumption in use, the use phase of 5 years accounts for approx. 54% of overall greenhouse gas emissions in Scenarios 3 and 4 and has the following effect upon the amortisation calculation:

- If a new notebook is 10% more energy-efficient than an old one, the greenhouse gas emissions arising from production, distribution and disposal would only pay back after 41 years of use (instead of 87 or 88 years in the base analysis).
- If the energy efficiency improvement of the new notebook is 70%, the amortisation period in scenarios 3 and 4 shortens from 12 or 13 years to 6 years.

Sensitivity 2: Consideration of the emissions of fluorinated compounds (FCs)[7] from display production

Studies suggest that in fabs without FC emissions treatment the GWP values of display production may be even higher than generally assumed [4]. The additional consideration of FC emissions results in a substantial increase of the GWP values for the display production by 22% (Table 7).

Table 7: Compilation of GWP values of display production of the base and sensitivity analyses, with consideration of FC emissions as compared to the base analyses of scenarios 3 and 4

Production of display module	**kg CO_2e/notebook display**
Base analysis (scenarios 3 and 4)	35.1
Sensitivity analysis 2	42.7
Deviation from base analysis in %	+21.7%

Consequently, if FC emissions are taken into account, production of the display module accounts for 11% of total greenhouse gas emissions. If FC emissions are not additionally considered, production of the display module accounts for only 9% of total greenhouse gas emissions. The use phase accounts for 35% of total greenhouse gas emissions in scenarios 3 and 4. Sensitivity 2 analysis for scenarios 3 and 4 has the following effect upon the amortisation calculation:

- If a new notebook is 10% more energy efficient than an old one, the greenhouse gas emissions arising from production, distribution and disposal would only pay back after 90 years of use (instead of 87 or 88 years in the base analysis).
- If the energy efficiency improvement of the new notebook is 70%, the amortisation period in Scenarios 3 and 4 is with 13 years nearly the same compared to the base analysis.

Sensitivity 3: Adjustment of useful lifetime to 2.9 years

If an overall lifetime of only 2.9 years is considered (compared to 5 years of the base analysis), the electricity consumption and GWP emissions in the use phase drop by 42%. The reduced GWP values in the use phase result in an overall decrease between 15 and 25% (Table 8).

Table 8: Results of sensitivity analysis 3 compared to the base analyses of all scenarios (Sc) examined

Total GWP of a notebook (kg CO_2e/notebook)	**EuP Lot3 (Sc 1)**	**EcoInvent 2.2 (Sc 2)**	**UFO-PLAN 2009 (Sc 3)**	**UFO-PLAN 2009 (Sc 4)**
Base analysis	230	362	382	380
Sensitivity analysis 3	172	304	324	322
Deviation from base analysis	–25%	–16%	–15%	–15%

Consequently, due to the reduced lifetime of the notebook, the use phase of scenarios 3 and 4 only accounts for approx. 24% of the total greenhouse gas emissions. In other words, if the lifetime of notebooks is extended, the share of the production, distribution and disposal phases in total

[7] In accordance with the Kyoto Protocol, “fluorinated greenhouse gases” comprise three groups of substances: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). In terms of chemistry there are further groups of substances that belong to fluorinated gases, such as the fluorinated ethers and nitrogen trifluoride (NF_3). These substances are not yet listed by the Kyoto Protocol, but their inclusion is under debate. Fluorinated greenhouse gases (F-gases) have a global warming impact that is 100 to 24,000 times greater than that of CO_2. The share of fluorinated greenhouse gases in the overall emissions of global warming gases is expected to grow threefold worldwide from its present proportion of just under 2% to around 6% by the year 2050. F-gases such as SF_6 and NF_3 are used in applications such as etching and cleaning gases for flat screen display, semiconductor and printed wiring board production [5].

greenhouse gas emissions is reduced. For this sensitivity analysis, the amortisation periods are the same to the basis scenario, since the GWP value in the upstream and downstream processes does not change compared with the basis scenario. The annual GWP value in the use phase, which is needed for the amortisation calculation, is also the same to the basis scenario. The reduced lifetime has only an impact on the total value and the proportion of the life phases.

Discussion

Results of this study show that the share of the production phase in the total GWP of a notebook varies according to the database used. The share of the production phase in the total GWP of a notebook was highest when the database of UFOPLAN 2009 was used, and lowest with the EuP Lot 3 database. It is also worth mentioning that the GWP of the production phase was higher not only as the percentage share of the total GWP, but also in absolute terms with the dataset of UFOPLAN 2009. It is also expected that variations in the GWP in scenarios 1 to 4 are attributed more to the differences between the datasets used, and less to the differences in the production processes.

The sensitivity analysis 1 shows that even if electricity consumption in the use phase is increased or doubled, the greenhouse gas emissions arising from the production phase remain substantial. Moreover, the comparison of different data sources demonstrates that EuP Lot 3 significantly underrates the material and energy inputs required to produce a notebook (81 kg CO_2e). Other studies find that the production-related emissions for the motherboard of a notebook alone are on the order of 70 kg CO_2e [6], [7] to 85 kg CO_2e [8]. Sensitivity analysis 3, in which the lifetime of a notebook was reduced to a period of 2.9 years, which is realistic under present market and consumption patterns [2], confirms that the use phase of a notebook only accounts for 25% of all greenhouse gas emissions.

Analysis of the end-of-life phase in this study distinguishes between business-as-usual and best practice. The difference between the greenhouse gas emissions of the two scenarios is minimal, being only 2 kg CO_2e. The reason why the high recovery rates with best practice recycling deliver only a minor reduction in greenhouse gas emissions compared to business-as-usual recycling is that the proportions of gold, silver and palladium contained in a notebook are small. If, however, we consider the overall number of notebooks present in Germany (stock in the residential and business sectors in 2009/2010: approx. 47 million notebooks) the potential for reduced environmental impacts would be significantly greater. Moreover, the potential to reduce impacts associated with the raw material extraction could be further increased if the following aspects were considered:

- Environmental effects such as acidification, eutrophication, resource consumption, biodiversity loss, toxicity etc.
- Social impacts, such as safe and healthy living conditions of the people living in the vicinity of extraction sites.
- Consideration of the secondary recovery of further precious and special metals. Existing high-tech facilities can in fact recover up to 17 different precious and special metals from e-scrap.
- Consideration of extreme scenarios such as notebook recycling and disposal in developing and newly industrialising countries where recycling infrastructures and technologies are under-developed.

The analysis of environmental amortisation periods has shown that the environmental impact associated with the production of a notebook is so great that it cannot be compensated in a realistic period of time by its savings through improved energy efficiency during the use phase – regardless of which data source is used. If we assume a realistic energy efficiency improvement of 10% between two notebook generations, the amortisation periods are between 33 and 88 years, while if energy efficiency improves by 20% the period is between 17 and 44 years, depending upon the data source used to analyse notebook production. Evidently, notebooks do not have such a long lifetime.

The study results suggest that from an environmental perspective (with regard to global warming potential) it is not reasonable to purchase a new notebook after a usage period of only a few years, even if the assumed energy efficiency of the new device exploits the full scope of cutting-edge technology.

Conclusions

The findings of this study confirm that the production phase has a significant contribution to the overall greenhouse gas emissions of a notebook and should therefore be placed in the focus of sustainable product policy. Until now, however, European eco-design policy for energy-using products (EuP) has focussed on improving energy efficiency or reducing energy consumption in the use phase.

For the notebook product group this focus is of only limited usefulness in achieving policy goals, as notebooks are already designed to have high levels of energy efficiency in order to achieve long running times and long lifetimes of the rechargeable batteries for mobile applications. Thus, the focus of mandatory product policy measures for ICT devices should be placed on the following aspects:

- Recycling-friendly design,
- Modular construction,
- Standardisation of components,
- Reduction of the energy consumption and GWP of the production phase,
- Possibilities of hardware upgrading,
- Extension of minimum warranty periods, and
- Availability of spare parts.

The recommendations mentioned above serve two major purposes: reducing the absolute impacts of the production phase and extending the total life-time of a notebook. Furthermore, St-Laurent et al. [10] describe that a common reason for computer replacement is that they cannot run recent software at a reasonable speed. Swan (citied in [10]) argues that software design practices and marketing strategies have worsened the problem of e-wastes. Hence, maintain or technical support of old software on the corresponding old devices should also be guaranteed to avoid the early replacement.

Finally, the focus of assessing the environmental impacts of ICT devices should not be limited to greenhouse gas emissions, but should be broadened to include other impact categories such as acidification and eutrophication potential, resource consumption, biodiversity loss, toxicity etc.

Outlook

The German federal government intends to reduce the energy consumption caused by ICT in Federal Administration Departments significantly. To achieve the quantitative saving potentials, policy makers and public buyers need robust bases for their decision-making regarding the choice for an environmentally friendly IT workplace. According to the study presented above, a decision for a prolonged usage of existing devices on the one side, or their substitution by more efficient products on the other side has to be taken.

Basis for robust political decision-making is a comprehensive knowledge about the environmental impacts of all life cycle phases of ICT products. ICT devices contain valuable materials like gold, silver, platinum group metals, indium etc., whose manufacturing is related to high environmental impacts. Only life cycle analyses address the whole range of those impacts. Thus, they are important instruments for the identification of optimization potentials. However, the current data basis regarding the resource consumption as well as the energy flows of ICT products in the up- and downstream production phases is insufficient. Due to technology dynamics, the existing data do not reflect state-of-the-art and require an update.

To improve the data basis and to derive robust recommendations for environmentally friendly IT workplaces in Federal Administration Departments, the Federal Environmental Agency has commissioned the scientific study „Environmental and economic aspects regarding the comparison of workstation computers used in Federal Administration Departments taking account of the user behaviour.“ [9]

Due to the complex and global supply chains as well as the short innovation cycles of ICT, the focus of the study will be on scalable life cycle data for the three components CPU, unfitted PCB and HDD. They account for a large share of the total carbon footprint of the products and contain a high proportion of important resources like rare metals. Besides the greenhouse gas potential, also the resource consumption of the selected components will be analysed. Current publicly available data, for example from databases, research studies, company and sector reports, statistical production data etc. build the basis for the calculations.

Further, it is assumed that the currently applied measurement methods and standards regarding the use profiles of ICT devices are not up to date. Key parameters are simplified so much that no realistic statements can be made about the use phase, for example the calculation of the Active Mode. Additionally it is expected that the improvements by power management functions will lead to an overall decreased energy consumption compared to the calculated average values of standards. Thus, the study will also analyse existing measurement concepts regarding their applicability to current ICT in order to build the calculation of the energy consumption of the use phase on a more realistic basis and potentially to derive revision needs of the methods. The desk research is supported by findings from real measurements conducted at a number of workstation computers in the Federal Agency for Environment, as well as two Advisory Commitees composed of experts from industry, science, and Federal Administrations.

The study results are expected to be finalised in late 2014.

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[7] O’Connell, S.; Stutz, M.; Product Carbon Footprint (PCF) Assessment of Dell Laptop – Results and Recommendations 2009; Sustainable Systems and Technology (ISSST), 2010 IEEE, ISBN: 978-1-4244-7094-5

[8] Tekawa M.; Miyamoto, S.; Inaba, A.; Life Cycle Assessment; an approach to environmentally friendly PCs, Proc IEEE Int Symp Electron Environ, May 5-7, San Francisco, CA, pp. 125-130

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Best available technology of plug-in refrigerated cabinets, beverage coolers and ice cream freezers and the challenges of measuring and comparing energy efficiency

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Abstract

Energy efficiency potentials for plug-in refrigerated cabinets, beverage coolers and ice cream freezers are shown by comparing typical and best models available on the market. A research project demonstrates efficiency potential when applying commercially available measures, and it investigates technologies for future improvements. This paper identifies the lack of a unified test methodology and energy efficiency rating system as challenges for energy saving initiatives in Europe. National and regional programmes for efficient refrigeration are portrayed. Their experiences can help the design of planned EU regulations. The programmes make implementing minimum requirements and energy labels faster and easier; for years they have raised awareness and supported manufacturers / importers to market high-efficiency products. One lesson to be learned from them is that market surveillance and verification tests are needed to ensure good data quality and fair product comparisons.

Efficiency potentials today

Comparing the energy efficiency of commercial and professional refrigerators and freezers is not easy because little data is available. To date there is no product information requirement on energy consumption for manufacturers. Topten International researched energy consumption data for four common plug-in product types: beverage coolers, ice cream freezers, storage refrigerators and storage freezers [1]. The first two types are display cabinets; the latter two are also known as refrigerated service cabinets or refrigerated storage cabinets (chilled and frozen).

Best-efficiency models available are identified and presented online under www.topten.eu > Professional Refrigerators [2]. Their energy consumption data is provided according to one of the following protocols: EN ISO 23953-2:2005, EN 441-1995 or CECED Italia Test protocol for professional refrigerators and freezers[1]. One valuable data source is the Energy Technology List (ETL) by the Department of Energy & Climate Change (DECC) in the United Kingdom [3].

Energy saving potentials are estimated by comparing best-efficiency models to typical models with comparable net volume. Display cabinets are also compared to open models since they are commonly used for selling beverages and ice cream. Again, the energy consumption data conforms to the above protocols.[2] A domestic model was also included in the comparison. Note that household appliances are subject to less demanding conditions and are designed and tested accordingly (static

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[1] The data is normalized based on the method described by Tait Consulting limited [7]

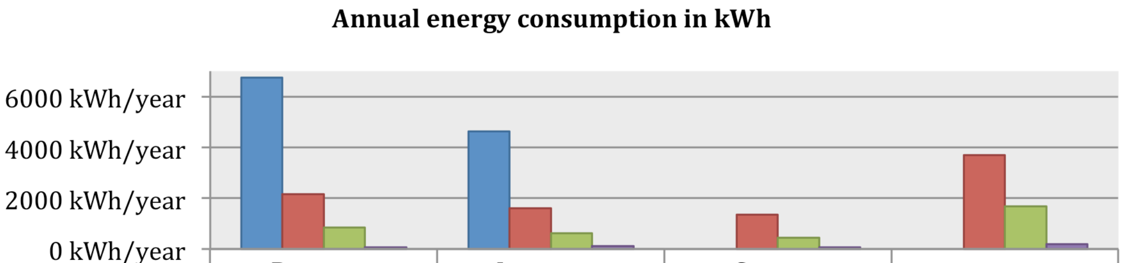
[2] In the case of the refrigerated service cabinets the base case from the preparatory study Lot 1 was used as the typical model [5]. In the case of the display cabinets newer product data from ETL was used as the typical model since the preparatory study Lot 12 for display cabinets [6] is over 5 years old. For the open models the energy consumption data is from the manufacturer's technical documentation. Although the test standard is unknown we consider the values valid for comparison since no door openings are necessary for testing open models.

cooling system, no door openings, no load, lower ambient temperature); these factors can halve the energy consumption determined.

The comparison is summarized in Figure 1. It shows that:

- Typical commercial and professional refrigerators / freezers use 2 – 3 times more energy than best-efficiency models available.
- Open display cabinets use 8 times more energy than best-efficiency models available.
- Domestic models use 5 – 10 times less energy than best-efficiency models available.

Energy saving potentials of best available technology (BAT) are between 54 – 67% in all cases. Replacing open cabinets with BAT display cabinets brings energy savings of 87% for both beverage coolers and ice cream freezers.



	Beverage cooler	Ice cream freezer	Storage refrigerator	Storage freezer
Open	6753 kWh/year	4636 kWh/year		
Typical closed	2168 kWh/year	1606 kWh/year	1348 kWh/year	3690 kWh/year
Best efficiency	859 kWh/year	615 kWh/year	439 kWh/year	1685 kWh/year
Domestic	75 kWh/year	117 kWh/year	75 kWh/year	193 kWh/year

Figure 1: Comparison of the annual energy consumption for an open cabinet (if applicable), a typical closed cabinet, a best-efficiency model and a domestic model with approximately the same net volume

The following three tables show the products used in the comparison.

Table 1: Comparison of 3 plug-in beverage coolers and a household refrigerator

	Open cooler	Typical glass door cooler	High-efficiency glass door cooler	Household refrigerator A+++
Net volume	324 liters	350 liters	346 liters	346 liters
Energy use	6753 kWh/year	2168 kWh/year	859 kWh/year	75 kWh/year
Electricity costs in 8 years (0.15 €/kWh)	8104 €	2602 €	1031 €	90 €
Refrigerant	R404A (high-GWP)	R134a (high-GWP)	R600a (low-GWP)	R600a (low-GWP)
				

Table 2: Comparison of 3 plug-in ice cream freezers and a household freezer chest

	Open ice cream freezer	**Typical glass top ice cream freezer**	**High-efficiency insulated top ice cream freezer**	**Household chest freezer A+++**
Net volume	151 liters	183 liters	224 liters	200 liters
Energy use	4636 kWh/year	1606 kWh/year	615 kWh/year	117 kWh/year
Electricity costs in 8 years (0.15 €/kWh)	5563 €	1927 €	738 €	140 €
Refrigerant	R404A (high-GWP)	R290 (low-GWP)	R290 (low-GWP)	R600a (low-GWP)
				

Table 3: Comparison of 2 plug-in refrigerated service cabinets and a domestic model (each for chilled and frozen)

	Typical storage refrigerator	**Best-efficiency storage refrigerator**	**Household refrigerator A+++**
Net volume	450 liters	449 liters	346 liters
Energy use	1348 kWh/year	439 kWh/year	75 kWh/year
Electricity costs in 8 years (0.15 €/kWh)	1618 €	527 €	90 €
Refrigerant	R134a (high-GWP)	R290 (low-GWP)	R600a (low-GWP)
			
	Typical storage freezer	**Best-efficiency storage freezer**	**Household upright freezer A+++**
Net volume	450 liters	449 liters	406 liters
Energy use	3690 kWh/year	1685 kWh/year	193 kWh/year
Electricity costs in 8 years (0.15 €/kWh)	4428 €	2022 €	232 €
Refrigerant	R404A (high-GWP)	R290 (low-GWP)	R600a (low-GWP)
			

Household refrigerators and freezers use 66% less energy than 20 years ago

Energy efficiency of household refrigerators and freezers has been a focus of European Union (EU) policies for almost 20 years. Today the lowest performing products allowed on the market are A+ compared to the initial lowest energy class G; this means a 66% decrease in energy consumption. More and more A+++ models are appearing on the market. They consume half the energy of typical A+ models sold today. Energy efficiency is still improving.

The household refrigerators and freezers success story raises hopes that similar energy savings can be realized for commercial and professional products.

There are 275 million household refrigerators and freezers in the EU; that is 23 times more than the professional plug-in products in this discussion (12 million units, see Table 4). Nonetheless, household refrigerators and freezers use only 4.5 times more energy.

Table 4: Stock and energy consumption in the EU

	Beverage coolers	**Ice cream freezers**	**Refrigerated service cabinets**	**Household refrigerators**	**Household freezers**
Stock in EU-27	6 million units	3 million units	3 million units	191 million units	84 million units
Energy consumption	16 TWh/year	4 TWh/year	7 TWh/year	82 TWh/year	40 TWh/year

Source: JRC Energy Efficiency Status Report [4]. Estimates are for the years 2007 (beverage coolers, ice cream freezers), 2008 (refrigerated service cabinets) and 2005 (household refrigerators/ freezers).

Summary of EU policies regarding energy efficiency of household refrigerators and freezers

As early as 1995 an energy label for household refrigerating appliances was introduced; it was redesigned in 2010 to reflect the changes in how appliances are rated regarding energy usage and efficiency and narrowing the measurement tolerance. Since 1999 household refrigerators and freezers must comply with minimum energy efficiency requirements in order to be placed on the market. These minimum energy efficiency requirements were revised and sharpened per July 2010. Since then, only class A or more efficient refrigerators and freezers are permitted on the EU market. Requirements were again tightened in 2012, and will be further tightened in 2014, introducing A+ as the minimum requirement in two steps (2012: Energy Efficiency Index (EEI) < 44, 2014: EEI < 42).

Expected future efficiencies based on on-going research and development

Design of plug-in commercial equipment has been mainly focused on costs throughout last decades and less on energy efficiency. As during recent years more attention has been paid by especially large end-users of such systems, such as beverage companies and beer brewers, more energy efficient products are entering the market. There are effectively a large number of energy saving measures feasible for such kind of products, several of these have been developed and implemented in domestic refrigerator products. A non-complete list of energy saving measures comprises:

a) More energy efficient compressors. Where a COP level of 1.8[3] is quite typical for a reasonably sized domestic refrigerator compressor today, this has been far above typical values for commercial refrigerator compressors, this despite the larger sizes these typically have. Based on customer requests, compressor manufacturers have developed more efficient compressors getting close to the efficiency of domestic refrigerator compressors. In addition variable speed compressors are entering the market which offer an additional energy saving potential.

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[3] At ASHRAE rating condition of 54.4/-23.3 °C and vapour/liquid temperatures of 32.2 °C

b) More efficient fans have been introduced with electronically commutated motors which may reduce the fan consumption with as much as a factor 3. As the power used by the evaporator fan is effectively transferred to heat inside of the cabinet, which subsequently has to be removed by the refrigeration system, the power reduction on the total system is about double of what has been gained by the fan itself.

c) Better insulating glass doors and thicker insulated walls.

d) Increased heat exchangers performances by increased sizing and improved designs.

e) Lighting systems are often used (especially in glass door coolers) which are being replaced with LED lighting. Also here a multiplying effect is present as the lighting power consumption is turned into heat in the product.

f) Energy Management Systems controllers which ensure that the compartment temperatures are higher during the stand-by mode periods (i.e. a time frame where the cooler is switched on but no products are taken / sold).

Substantial energy saving by combinations of the measures quoted above are quite feasible. As an example, Re/genT is involved with a EU 7th framework research project called iCool, which already has demonstrated a reduction of a typical glass door cooler with a consumption of 3.9 kWh/day to a level of 0.9 kWh/day by commercially available measures; this means 77% energy savings. Further improvements are investigated in the iCool project such as the use of phase change materials to cover the peak heat loads of an appliance when it is loaded with warm products (see http://www.icool.fp7.co/ for more details).

Challenges of measuring and comparing energy efficiency

Comparing product data on energy consumption is quite complex today because no product information requirement exists. The values in catalogues and on manufacturer websites cannot be compared between brands. Manufacturers generally test energy consumption according to their own criteria. Details about the test methodologies are often unknown. In some cases the methodology might resemble EN 153 for testing household refrigerators (e.g. no door openings, no control of inside temperatures, lower ambient temperature). This leads to significantly lower energy consumption values. Figure 2 shows the big difference in energy consumption values found in the catalogue and tested according to the standard EN 441-1995 for the same model.

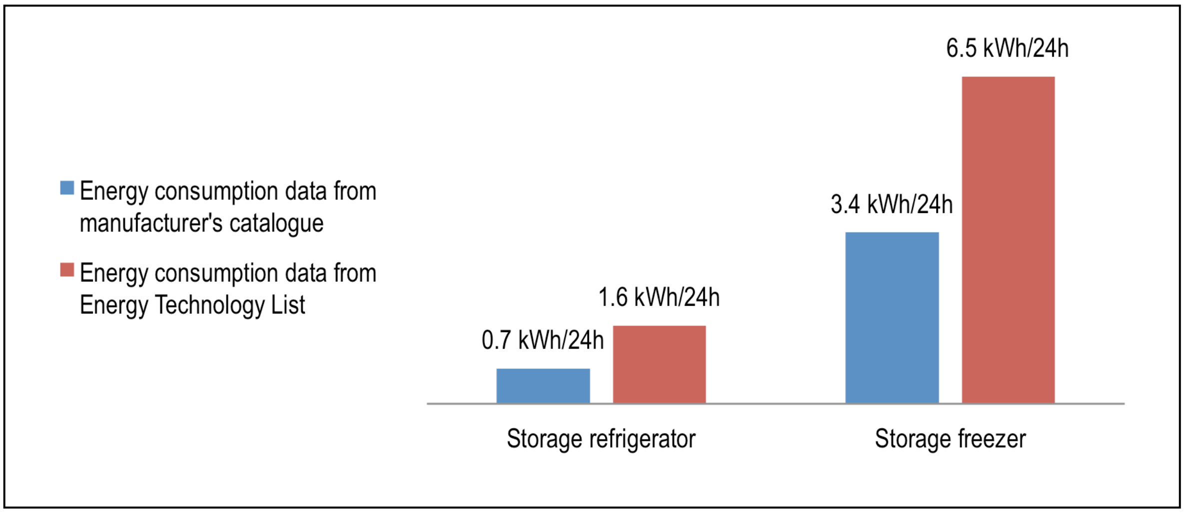


Figure 2: Energy consumption values for the same models found in the manufacturer's catalogue and tested according to EN 441-1995.

International test standards do exist, but these are, at a European level, almost exclusively used to determine compliance with national and regional programmes. Display cabinets, including beverage coolers and ice cream freezers, are covered by EN ISO 23953-2005, of which an amended version was published in May 2012 (EN ISO 23953-2005/A1:2012). A new test standard for refrigerated service cabinets is currently being developed by a CEN TC44 working group; the final version is targeted for the end of 2013. There are two other test protocols used for service cabinets: EN 441-1995, which preceded EN ISO 23953-2005[4], and the CECED Italia test protocol for professional refrigerators and freezers.

The acceptable temperature range for the load (so called M-packages) is described as temperature class in the test. The programmes portrayed below require products to conform to temperature class M1 for chilled goods (-1°C to +5°C) and L1 for frozen goods (-18°C to -15°C). Another commonly required temperature class is M2 (-1°C to +7°C); the test standards give a choice of 7 pre-set temperature classes.

The test standards also give a choice of 8 climate classes. They indicate the tolerable range for ambient temperature and relative humidity in the testing chamber. All the national and regional programmes require climate class 3 (ambient temperature 25°C, 60% humidity) for display cabinets and 4 (ambient temperature 30°C, 55% humidity) for service cabinets. Manufacturers might select a different climate class for use in their own product testing activities.

There are differences in the test protocols for cabinet door opening frequency in each of the standards. In general display cabinets are prescribed to be opened more often than service cabinets, and chilled cabinets are prescribed to be opened more often than frozen cabinets. Test protocols also differ regarding door opening time. Taken together these factors affect energy consumption measurements. Results due to EN 441-1995 are, in general, slightly higher than those measured according to EN ISO 23953-2005 and CECED Italia[5]. Doors are kept open for longer periods, allowing more infiltration of warm air and humidity.

Table 5: Single door opening behaviour: differences in test protocols

Test protocol	Test duration with door openings (hours)	Duration initial door opening (minutes)	Duration further door openings (seconds)	Door is opened every … minutes	Total duration of door kept open (seconds per 24 hours)
CECED Italia - chilled cabinets + counter freezers	12	2	6	10	552
CECED Italia - vertical freezers	2 x 4[6]	2 x 1	6	10	408
EN 441-1995	12	3	12	10	1044
EN ISO 23953-2:2005[7]	12	3	6	10	612
EN ISO 23953-2:2005 /A1:2012 - chilled cabinets	12	3	15	13	1260
EN ISO 23953-2:2005 /A1:2012 - frozen cabinets	12	3	6	10	612

[4] The scope of EN ISO 23953-2005 is refrigerated display cabinets; that is why it was not well accepted for testing service cabinets and manufacturers as well as energy saving programmes continue to use EN 441-1995, even if it was officially replaced.

[5] In their newest working document on ecodesign requirements for refrigerated service cabinets the European Commission suggests a test protocol that corresponds to CECED Italia.

[6] With a 4 hour break in between

[7] Same single door opening behaviour as in the Australian standard AS 1731.5-2003

Strategies for market transformation

The European Commission plans to regulate ecodesign and energy labelling for several professional and commercial refrigeration product groups. Draft regulations exist for 5 product groups affiliated in DG ENTR Lot 1: refrigerated service cabinets, blast cabinets, walk-in cold rooms up to 400m3, refrigeration process chillers and remote condensing units. It is expected that these regulations will be adopted by the end of 2013. An energy label and minimum energy efficiency requirements are proposed for refrigerated service cabinets. Initially they were targeted to be applied from July 2014. In the most recent drafts the date of application has been delayed by one year to July 2015.

The European Commission with assistance from the Joint Research Centre, Institute for Prospective Technological Studies (JRC-IPTS), is currently updating the 2007 preparatory study for ENER Lot 12 commercial refrigerators and freezers: refrigerated display cabinets (remote and plug-in) including ice cream freezers and vending machines.

National and regional programmes for promoting energy efficiency in commercial and professional refrigeration products have been going on in the UK, Denmark, Switzerland and Italy for many years. These programmes lead the way in delivering energy savings on a European level and support the EU regulatory process. They will be portrayed in the following chapters. Table 6 gives an overview.

Table 6: Programme overview: products covered, eligible energy consumption data

Programme	Energy Technology List (UK)	Energy Technology List (UK)	The Danish Energy Saving Trust/ Go' Energi	topten.ch (Switzerland) and topten.eu (Europe)	topten.ch (Switzerland) and topten.eu (Europe)	CECED Italia
Product list name	Commercial Service Cabinets	Refrigerated Display Cabinets	Commercial fridges / Commercial freezers	Glass door refrigerators / Ice cream freezers / Supermarket freezers	Storage refrigerators / Storage freezers	(no publicly available product list)
Active since	2003	2003	2005	2012	2012	2012
Products covered						
Type	plug-in only	remote + plug-in	plug-in only	plug-in only	plug-in only	plug-in only
Door / lid	insulated	glass	insulated	glass / insulated	insulated	insulated
Open cabinets	no	yes	no	no	no	no
Refrigerant	no requirement	no requirement	no requirement	only GWP < 5 (R290, R600a) [8]	only GWP < 5 (R290, R600a)	no requirement
Extent	236[9] models of 13 brands	970[9] models of 39 brands	46 models of 5 brands	7 models of 2 brands	CH: 48 models of 3 brands; Europe: 73 mod. of 3 brands	793 models of 5 brands
Eligible energy consumption data						
Primary test standard	EN 441-1995	EN ISO 23953-2005	EN 441-1995	EN ISO 23953-2005(/A1:2012)[10]	CECED Italia Test protocol for professional refrigerators and freezers	CECED Italia Test protocol for professional refrigerators and freezers[11]

8 Other low-GWP refrigerants like CO2 (R744) would be eligible, but no such products have been registered at Topten so far.

9 Since the scheme's inception over 1550 refrigerated display cabinets (RDC) have been assessed for inclusion. Approximately 20% of proposed RDC products did not meet the criteria. Products are removed from the ETL when the underlying technology category performance criteria are made more stringent. Similarly, some 25% of commercial service cabinets failed to make the grade and the remaining 75% - some 273 products - were verified to be eligible

10 As of today no product data according to the 2012 version has been registered at Topten.

11 The CECED Italia test protocol is based on EN ISO 23953-2:2005, but door openings have been altered: the duration of the initial door opening is only 2 minutes and for vertical freezers door openings are performed during only 8 hours.

Other accepted test standards	none	none	EN ISO 23953-2005 (correction factor 1.1)	EN 441-1995 (correction factor 0.91)	EN 441-1995 or EN ISO 23953-2005 (correction factors 0.8-1[12])	none
Test condition: climate class of testing chamber	4 (ambient temperature 30°C, 55% humidity)	3 (ambient temperature 25°C, 60% humidity)	4 (ambient temperature 30°C, 55% humidity)	3 (ambient temperature 25°C, 60% humidity)	4 (ambient temperature 30°C, 55% humidity)	4 (ambient temperature 30°C, 55% humidity)

The programmes are coordinated to some extent, and therefore it is possible for the manufacturer / importer to use the same test reports for identical models supported under different programmes.

The Danish and the Topten programmes accept data according to more than one test standard. As described above, the energy consumption measurements vary between test standards and must therefore be adjusted.

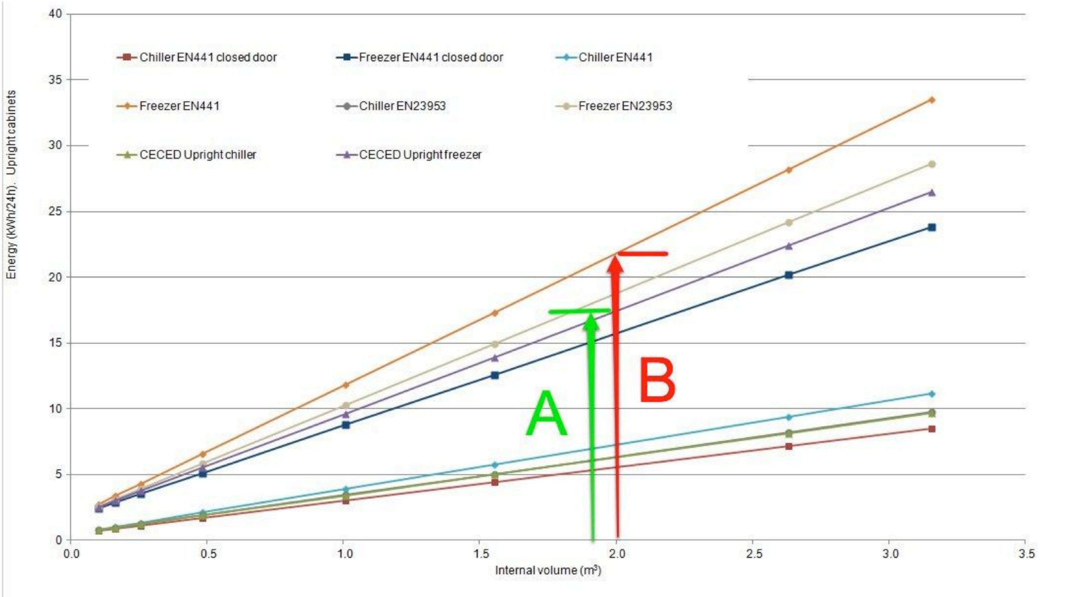
Correction factors to adjust energy consumption between test standards

The Danish Technological Institute (DTI) tested 2 refrigerated service cabinets (1 refrigerator, 1 freezer) according to EN 441-1995 and EN ISO 23953-2005. The energy consumption was 9.7% lower for the refrigerator and 7.1% lower for the freezer when measured according to EN ISO 23953-2005. With this result a correction factor of 1.1 for energy consumption tested according to EN ISO 23953-2005 was set for the Danish programme.

The Carbon Trust tested 7 commercial service cabinets with volumes between 0.37 m3 and 0.57m3 (3 L1 and 4 M1 class) and 6 refrigerated display cabinets with total display area (TDA) between 0.21 m2 to 1.33 m2 (4 L1 and 2 M2 class) according to EN 441-1995 and EN ISO 23953-2005. For refrigerated display cabinets the energy consumption measured was between 4% more and 12% less under EN ISO 23953-2005 (although an outlier of 18% more was observed), and for commercial service cabinets it was between 0% and 43% less. Based only in part on these test results, the use of EN ISO 23953-2005 was not adopted for ETL compliance of commercial service cabinets.

A document by Tait Consulting for the ecodesign regulation impact assessment study in May 2012 [7] describes how to proportion energy consumption between EN 441-1995, EN ISO 23953-2005 and the CECED Italia test protocol. The proportions were derived from a data set of over 3000 products. Figure 3 shows a graph and description of the methodology. The Topten programme derived correction factors based on this methodology.

[12] see http://www.topten.eu/english/criteria/professional-storage-refrigerators.html



As an example calculation step: in Figure 8 the energy consumed by a 2 m^3 upright freezer cabinet tested according to EN441 is around 22 kWh (dimension B) per 24 hours; and for the same cabinet under CECED Italia 17.5 kWh (dimension A). So a test result under EN441 should be adjusted by the ratio:

Test result as if under CECED Italia = [Test result under EN441] x (A / B)

Figure 3: Graph demonstrating how to adjust energy consumption between different test standards

Source: Performance Data Normalisation Methodology for Professional Storage Cabinets, Tait Consulting [7].

Tests to verify product data

In the UK, the Carbon Trust has tested a number of cabinets listed on the Energy Technology List. On three separate occasions groups of refrigerated display cabinets and commercial service cabinets have been tested. Approximately 10% of commercial service cabinets and 5% of refrigerated display cabinets have been independently tested to confirm compliance to ETL performance criteria. The very significant majority passed ETL compliance testing.

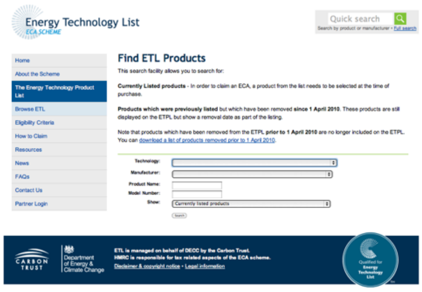
The Danish Technological Institute has also conducted a number of accredited tests to verify product data. The Danish Energy Saving Trust / Go' Energi picked the models for testing and asked manufacturers / importers to give the serial numbers for three appliances from their storage. The Trust / Go' Energi then decided which one of the three to test. From 2005 to 2011 a total of 12 models were tested. 4 models failed; the test result showed that they do not comply with the criteria and the models were removed from the lists.

The CECED Italia committee selects representative samples that are tested by an independent laboratory before manufacturers are allowed to label the products. The approximate cost of 6000 Euro (excl. VAT of 21%) per product tested is covered by the manufacturer. It is foreseen that participating manufacturers will test one model annually at an independent laboratory; this will cost about 3000 Euro (excl. VAT of 21%).

Topten Switzerland intends to test 2-3 models every year to be able to check manufacturers' declarations.

UK: Energy Technology List

The Energy Technology List (ETL) is part of the Enhanced Capital Allowance Scheme for Energy-Saving Technologies (ECA Scheme) and operates in the UK. It is a tax break scheme that enables businesses to claim a 100% first year capital allowance on investments in ETL products against the taxable profits from that period of investment. The ETL covers 58 technologies and over 16'600 qualifying products.



The ECA scheme began in 2003 and, after 10 years, continues to remain impactful in the UK cabinet market. The ETL is managed by the Carbon Trust on behalf of the Government (Department of Energy & Climate Change (DECC)).

Dissemination

Website: An ETL Website has existed since 2001 and is a key source of information on energy saving products. Each month over 10'000 users visit the site to check product information or learn more about energy saving technologies. In any one year the site has over 120'000 visitors who view over a million webpages. A range of publications focused upon a customer purchasing ETL products are available on the website; manufacturers and suppliers use them in pre-sales activities.

Label: Manufacturers or their suppliers can differentiate their products with the ETL logo. It is widely used in websites, data sheets, sales brochures, etc.

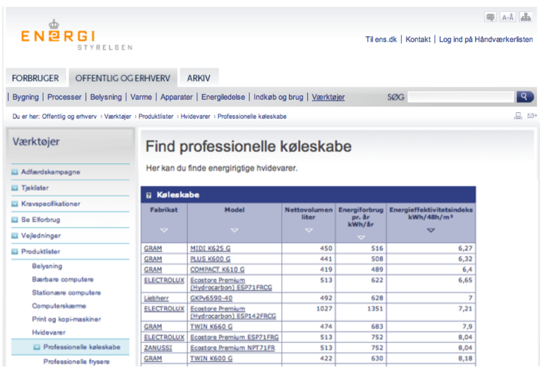
Stakeholder events: The Carbon Trust holds several events each year to ensure manufacturers or suppliers remain engaged in communicating the benefits of ETL technologies to their customers. Discussions include estimated impacts for the trading year (April to March), products added or removed, and coming changes.

Rationale behind criteria

The criteria for commercial service cabinets (CSC) and refrigerated display cabinets (RDC) are designed to support the top 25% of the market[13]. They were tightened in 2004 and 2008 for CSC, and in 2004, 2008 and 2013 for RDC, to adapt to product improvements. Minor changes were made in other years to clarify ambiguities; in total CSC and RDC criteria have each been updated 6 times.

Denmark: The Danish Energy Saving Trust and Go'Energi

The lists had been operated from the beginning in 2005 by the Danish Electricity Saving Trust and later on Go'Energi, which both were governmental institutions. A label "Recommended by Go'Energi" helped manufacturers and importers to market their products.



The list stopped in Spring 2013 due to lack of resources and decisions by the Danish Energy Agency to upgrade the work supporting EU Ecodesign and energy labeling systems. The label cannot be used since April 1st.

[13] In general, the ECA scheme criteria are set to meet the top 25% of the market. More rigorous criteria (top 10%) are used in some markets to encourage innovation.

The list remained available until May 31st under
http://www.ens.dk/offentlig-og-erhverv/vaerktoejer/produktlister/hvidevarelister

The scheme is coordinated with the corresponding UK scheme and therefore it was possible for the manufacturer/importer to use the test reports that were also used in the UK scheme if the cabinets are identical.

Dissemination

Label to use for manufacturers/importers: The appliances have been marketed and sold with help of recommendations from Danish Electricity Saving Trust and Go'Energi. It has been possible to place a label on the appliances: "Recommended by Go'Energi". This has been very efficient, and the products are believed to have had a marked share of at least 80 %. The remaining part of the marked consists of cheaper less efficient appliances.

Website: The product lists are presented with photos and technical data. Also selection criteria, user advice and purchase tips can be found there. The website has been very important for dissemination – especially because the manufacturers and the big suppliers used it as a part of their marketing campaigns.

TV and internet commercials: To support the communication of manufacturers/importers and raise awareness for the label, the Danish Electricity Saving Trust and Go'Energi advertised the label in TV and internet commercials.

Rationale behind criteria

The criteria were negotiated between the Danish Energy Saving Trust and the Danish Association of Contract Kitchen Equipment Suppliers. They are similar to the UK criteria.

Switzerland: Topten and regional rebate programmes

Topten originated in Switzerland and is now a global initiative coordinated by the Topten International Group (www.topten.info, [8]). It is a voluntary, non-profit project aiming to stimulate demand for the most energy efficient products in national markets. Topten is active in 17 European countries (funded by Intelligent Energy Europe (IEE) and coordinated by ADEME), China and USA.

Since 2010 Topten Switzerland together with eight cities and electricity utilities has been working on a project to promote efficient professional refrigeration products. Starting September 2013 five of the partner cities and electricity utilities plan to implement 3-year rebate programmes.

Dissemination

Financial incentives: Rebates of 160 to 1450 Euro[14] will be paid when buying a refrigerator or freezer from the Topten lists. Approximately 4500 cabinets will profit from this programme. Rebates will multiply communication as partner cities and utilities advertise in their region. Swiss suppliers will inform customers about rebates in sales conversations and marketing.

Website: From the Topten homepage, buyers can find all product lists with one simple click. High-efficiency products are represented with photos, technical data, an "inefficient" product for

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[14] The rebate depends on the product type (catalogue prices range from 900 to 5000 Euro) and is limited to a maximum of 25% of the paid price as stated on the receipt.

comparison, selection criteria, user advice and purchase tips, downloads and links to publications, standards and labels. Swiss market lists are available in German, French and Italian. www.topten.ch is well received and used (statistics: 1 mio. visits with 47 mio. hits in 2012).

Product lists are also available in English at www.topten.eu: Professional Refrigerators[15].

Media: Topten advises on best products and usage by offering expertise for professional articles, radio and TV shows. In 2012 Topten Switzerland had over 40 mio. media contacts.

Rationale behind criteria

As technologies improve, Topten criteria become stricter; lists stay limited to the 10 or so best products in each class.

Italy: CECED Italia

CECED Italia is the Italian Association of Home and Professional Appliances Manufacturers. Members of CECED Italia anticipated the forthcoming EU energy labeling regulations by voluntarily setting up a system for the energy efficiency classification of professional cabinets and counters.

Companies participating in the project have started to label their professional cabinets and counters to allow an objective evaluation of the products' efficiency for their customers.

CECED Italia in cooperation with the test laboratory IMQ has set up a voluntary evaluation and testing protocol based on EN ISO 23953-2, with adaptations on volume calculation and testing conditions (e.g. door opening frequency, loading patterns).

Dissemination

Label to use for manufacturers/importers: Participating manufacturers use the E.C.E. label to market their products.

Rationale behind energy efficiency classification

The label classifies energy efficiency on a scale from 7 (best) to 1 (worst). It is similar to the classical A to G scale of the EU energy label. One step up means an improvement of efficiency by 10 to 20%. The energy efficiency index (EEI) 100 stands for the typical model; it is the class threshold between 4 and 3. The thresholds were based upon a data set with several hundred models from four manufacturers.

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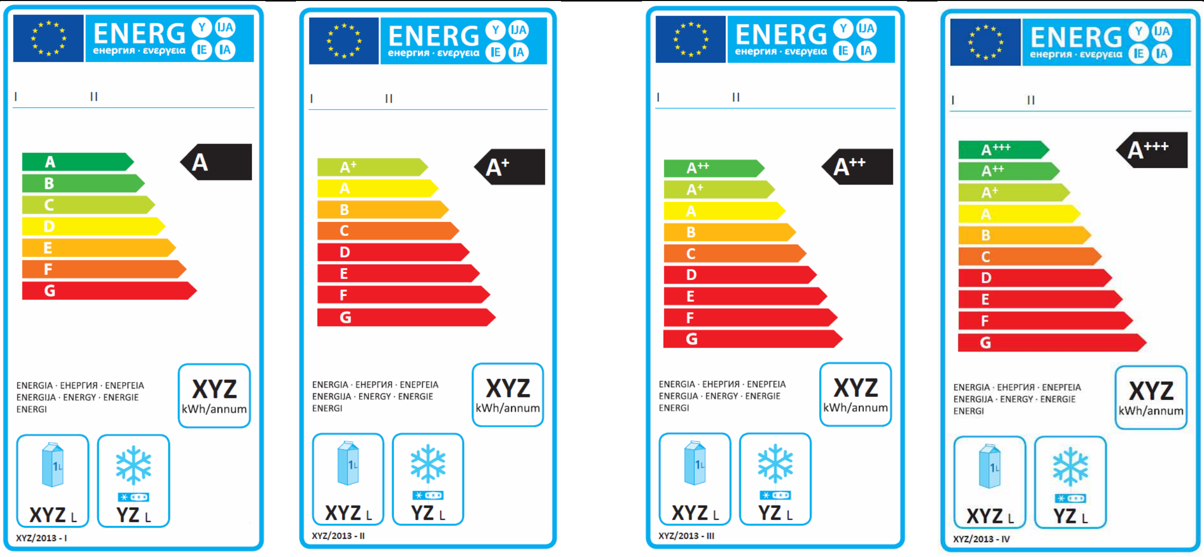
[15] The criteria for energy consumption are less strict for the European market and therefore more models are listed.

Proposed EU energy label

Starting 1st July 2015 an energy label and a product fiche shall be provided for professional storage cabinets. One year later A+ shall be added as top class. A++ shall be added in 2018 and A+++ in 2019. The energy label will indicate the annual energy consumption and the storage volumes. It will not show if the refrigerant used in the cabinet has high or low global warming potential (GWP).



Newest draft regulation from June 2013:			
1st July 2015	1st July 2016	1st July 2018	1st July 2019
Last draft regulation from June 2012:			
July 2014	January 2015	January 2016	January 2018

Table 7: Timetable for the energy label

The energy efficiency classes are defined as shown in Table 8.

Table 8: Proposed energy label classes

Class	Energy Efficiency Index (EEI)
A+++	< 15
A++	15-20
A+	20-30
A	30-40
B	40-55
C	55-75
D	75-90
E	90-100
F	100-110
G	110-125

Draft ecodesign regulation

The draft ecodesign regulation distinguishes between heavy- and light-duty cabinets. Light-duty cabinets by definition are capable of maintaining their operating temperature in an ambient temperature of 25°C and 60% relative humidity (climate class 3) but not in 30°C and 55% relative humidity (climate class 4). Heavy-duty cabinets perform well in ambient conditions that correspond to climate class 4 (typical for restaurant kitchens).

In the draft regulation annex III the measurement method for energy consumption is described including door openings (corresponding to the CECED Italia test protocol), ambient conditions (climate class 3 for light-duty cabinets, climate class 4 for heavy-duty cabinets), required temperatures of test packages and more. The calculation of the net volume is also described in detail.

For heavy-duty cabinets one single stage of energy efficiency requirements is proposed from 1st July 2015. Models worse than energy efficiency class G would then be phased out. For light-duty cabinets three stages of energy efficiency requirements are proposed:

- From 1 July 2015: EEI < 125 (phase out worse than G)
- From 1 July 2016: EEI < 110 (phase out G)
- From 1 July 2018: EEI < 100 (phase out F)

Product information requirements proposed for 1st July 2015 onward include all information needed to evaluate energy efficiency as well as the global warming potential of the refrigerant.

Summary

54% to 87% energy saving potential today and room for improvement

The product comparison by Topten International shows that 54 – 67% of energy consumption could be saved if best-efficiency models were used instead of the current typical models. Choosing best-efficiency display cabinets over open cabinets brings energy savings of 87%.

The research project iCool found that commercially available measures can reduce a typical glass door cooler's energy consumption by 77%. Phase change materials could further increase energy savings in the future.

Household refrigerators and freezers decreased their energy consumption by 66% since energy labelling and ecodesign measures have been applied. Beyond this significant improvement, new best-efficiency models offer a further 50% energy saving potential.

These combined findings raise hopes that plug-in commercial and professional refrigerators / freezers will halve their energy consumption once EU policies have been adopted.

Existing programmes will ease market integration of the EU energy label

There are already widely known programmes in European countries that steer towards energy efficient products. Manufacturers act as multipliers for dissemination as these programmes support their marketing. Financial incentives offered by governments, cities and utilities encourage buyers, dealers and manufacturers to push for more energy efficient products. Planned EU energy labels and minimum requirements will be more quickly integrated by manufacturers and suppliers.

The European Commission can unify procedures and ensure quality product information

This paper identifies the lack of unified test methodology and energy efficiency rating system as challenges for energy saving initiatives in Europe. The European Commission and the standardisation organisation CEN are working towards unifying the procedures.

There will be a period when product data from different test protocols will have to be adjusted for comparison. The European Commission could issue a guideline document similar to the data analysis in *Performance Data Normalisation Methodology for Professional Storage Cabinets* by Tait Consulting [7].

One lesson to be learned from national and regional programmes is that verification tests are needed to ensure good data quality and fair product comparisons. Market surveillance should be a substantial part of EU policies.

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Efficiency strategies assessment for three appliances in the residential sector: refrigerator, dishwashing and washing machines

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Abstract

The residential sector has become an important sector on what global energy consumption is concerned. Therefore, several policies have been developed towards the increase of efficiency in the residential appliances and, moreover, towards the increase of efficient consumption behaviors. Few policies, though, propose consumption strategies that change the usual operating cycles of the appliances.

This paper assesses the potentiality of improving the residential energy efficiency and cost savings through operational strategies for three appliances: refrigerator, dishwashing and washing machines. The approaches and main conclusions follow:

- Shifting the consumption of two refrigerators from "peak" periods: consumption increases 4.6 to 9.9% and costs raise 2.6 to 7.0%, depending on the refrigerator and chosen schedule;
- Connecting the dishwashing and washing machines to a pipe where water is heated by a gas heater: costs increase 23 and 82.5% and the CO_2 emissions 20 and 60%, respectively. If consumption to heat the water is not needed, the energy consumption would decrease until 89%;

Hereupon, results show that both strategies do not reduce consumption for energy and economic points of view. In order to reach more representative values, further experiments with more households and controlled parameters would be required.

Introduction

This paper wishes to contribute to the development of energy efficiency strategies in the residential energy consumption behaviors through *in situ* experiments regarding a dishwasher a clothes washing machine and two refrigerators. These appliances account for a significant share in the total electricity consumption and in 2004 they were characterized by 3%, 5% and 22%, respectively [1].

Energy efficiency is a World's top agenda issue, namely in the building sector as it now represents 40% of the total primary energy that is being consumed in the world [2]. It is well stated that consumption behavior habits have a strong impact in the overall efficiency, especially in the residential sector, and so several campaigns have been developed to induce more efficient behaviors by exposing common inefficiencies and common strategies to tackle them (*e.g.* "switch your incandescent light bulbs in your house by more efficient ones, such as fluorescents") [3].

Proper energy efficiency methodologies to be applied to the final consumer are currently seek so that more global policies can be accomplished, such one of the the 20-20-20 goals defined by the European Commission that aims at reducing 20% of the energy consumption through increasing energy efficiency [4]. The strong potential with the reinforcement of more efficient consumption habits is scattered among a wide range of consumers, having 78.4% of them simple-rate tariff contracts [5], which may glimpse the lack of initiative by the consumers to gather more efficient consumption habits in their lives.

Several strategies can be applied to the consumption behavior side in order to improve the overall energy efficiency in a household. This paper tests strategies that are stated as boosting energy performance in the three previously mentioned appliances: refrigerator, washer and dishwasher.

[6] affirmed in his talk that economic benefits can outcome from the forced switch off/on of the refrigerator in strategic periods of the day. This is justified for the operation interruption during peak periods, which are highly charged in hour-sensitive tariffs, and a further switch on during low peak periods. Due to these tariffs, economic benefits may outcome to the consumer. On the other hand, during these periods in which electricity consumption is more intensive, also a lower energy efficiency occurs due to electricity losses during the distribution cables as a consequence of more resistance. Having so, this strategy of reducing consumption during peak periods is proven to be a benefit to the utilities. Therefore, this paper tests the performance of two different refrigerators with the forced switch on/off in strategic periods of the day.

It is found in [7] that by connecting a washer or dishwasher to the hot water pipe, in which water is heated by a gas water heater, is a strategy to decrease electricity consumption of these appliances. A dishwasher operates with an initial water feed and heat, followed by a water dispersion cycle. A new heating process occurs after a water renewal. These two heating processes are responsible for most of the electricity that is consumed in the whole cycle. Accordingly, also the washing machine has an initial heating cycle after the water intake and a further rotation cycle to wash the clothes. Beyond the particularity of consuming more water, the electricity consumption in this appliance during the heat process is also the main parcel of the whole cycle. Hereupon, by decreasing the electricity consumption during the heating phases (70%-90% of the whole electricity that is consumed) in the washer and in the dishwasher by a different heat source, [7] states that this can reduce the electricity consumption. This paper addresses this issue by connecting a dishwasher and a washer to the heat water pipe and analyze the tradeoff with natural gas consumption to heat water.

This paper was developed under the framework of a project named NetZero Energy School, a partnership between Instituto das Ciências Sociais (Social Sciences Institute), Laboratório Nacional da Engenharia Civil (Civil Engineering National Laboratory), QUERCUS (an Environment protection Portuguese association), under the coordination of the MIT Portugal Program. This project aims at promoting energy awareness among a High School population, namely in the households of fifty families and the strategies that are tested in this paper are aligned with the awareness increase purpose.

Experimental

The experimental section is divided in two parts concerning the management of the usage of the appliances: refrigerator, and dishwashing and washing machines, in order to determine if the following proposals are environmentally and economically benefic:

- Turning off the refrigerator across few periods of the day;
- Connecting the washing and the dishwashing machines to the hot water pipe (the same as the hot water tap of the kitchen), instead of the regular cold water pipe, during the working time.

The electricity consumption of the appliances was measured with one *smart plug* – PlugMeter®, which provided data with a time resolution of 1 minute and the ability of scheduling the operating periods of the refrigerator.

Refrigerators

The study focused on two refrigerators:

- One, placed in a household, which is a BOSCH KGN46A03, with energy labeling A+ [9], compressor power of 150 W, refrigeration heater power of 220 W, freezing capacity of 82 L and refrigerating capacity of 264 L [8]. This refrigerator is a combined one, meaning that it has a freezer partition bigger than a regular refrigerator;
- Another, placed in the MIT Portugal Program offices, at the IST campus TagusPark, which is an INDESIT R 28, with energy labeling B, total power of 150 W, freezing capacity of 63 L and refrigerating capacity of 211 L [9]. This refrigerator has a lower energy label than the BOSCH but less than half of its power and lower volume capacity as well.

Three operating schedules were tested:

(i) Working continuously;

(ii) Disconnected from 9 to 10 h and from 15 to 16 h. These periods correspond to the highest intensity consumption periods, at a national level [10];

(iii) Disconnected from 22 to 0 h. These periods correspond to the highest intensity consumption periods, at the residential level [10].

Mitigation of the temperature effect in the different experiments

Since indoor temperature can influence the refrigerator consumption, this parameter had to be known in order to correct the electricity consumption in the different experimental periods for the same temperature. Unfortunately, it could not be measured during the experiment. However, shortly after the experiment, it was then possible to measure the indoor temperatures of the rooms and those values were crossed with the registered temperatures in Barcarena and Amadora weather stations in [11]. It was then perceived that the weekly variation of the indoor temperature is roughly half of the outdoor one and so this served as an approximation of the room temperature during the experiment.

In [12], for tests under approximately the same experimental conditions, the consumption varies according to: *(0.05T-0.47) [kWh/24h]*, where T is the temperature in the room. This is the variation assumed by the author. Unfortunately, the temperature inside the rooms was not measured because, at the time of the measurements, the author was not available to measure regularly the temperature and there was not any thermometer with data storage availability. So, the approximation made was as follows:

- The temperatures registered during the experimental period were collected in [11], using the registered data of the closest stations of TagusPark campus (Barcarena station – 1.5 km) and the experimental household (Amadora station – 4 km);

- The previous point was repeated for the first two weeks of September and the room temperature (in TagusPark room and in the household kitchen) of this period was measured during the day with a thermometer. Then, this temperature was crossed with that registered in [11] and a relation was established:

  - For the TagusPark campus, the measured temperature variation, during the day, is very mild (having a constant increase of the temperature until the end of the afternoon). But, as the average weekly temperature increases, the temperature inside the room increases approximately at the same rate. Thus, the average temperature collected for the tests will be considered as having the same variation as the room temperature, which is a fair approximation because, in that room, the sun strikes directly in the afternoon and the air conditioning is not usually turned on and the window is commonly opened.

  - For the kitchen in the experimental household, the measured temperature also varies slightly during the day, increasing until the end of the afternoon, but it is not as high as the average registered in [11]. The weekly increase of the outside temperature reflects a lower increase of the room temperature. This is a fair approximation because the kitchen does not have the sun striking directly, though the windows are frequently opened and has no air conditioning. Still, the house has a rather good thermal isolation. Therefore, the week variation of the room temperature will be considered as half of the temperature variation registered in [11].

Though this approach does not correspond to the real values that could be measured, it must be understood that, even if the temperatures in the weather stations are not the same as the outside temperature in the studied sets, the weekly amplitude shall be approximate in both places, what gives a reasonable accuracy to this methodology.

Dishwasher and washing machines

The measurements concerned the consumption of:

- A dishwasher, which is a BOSCH, model SMS40M02EU [13];
- A clothes washing machine, which is a SIEMENS, model WM10E120EE [14].

Two scenarios were simulated for each machine:

(i) Working at the programs A, B and C, in a selected program;

(ii) Working at the programs A, B and C, with water coming from the pipe in which the water is previously heated by the water heater by combustion of natural gas.

In each scenario, three programs were tested:

A. Dishwashing machine, working in program at 70^{o}C;

B. Dishwashing machine, working in program auto at 45-65^{o}C;

C. Washing machine, working in program at 40^{o}C.

Program A operates with 12 L, whereas program B operates with the consumption of 17 L per cycle. As it is shown in the Results section, the low water consumption in program A means a low water flow as well, whenever water is consumed, which is not enough to activate the gas water heater every time water is consumed. This is the reason why another program was tested in the dishwasher experiment, so that a higher water flow would exist and all the feeding water could activate the gas water heater.

Estimate of the water temperature variation

Since scenario (ii) concerns a test in which the feeding water is previously heated with a gas water heater, a careful analysis of this process has to be undertaken so that the heat efficiency can be modeled and consequently the temperature of the water at the entrance point of the machine. With this, and knowing the temperature of the water that is required by any selected program, the electricity that is consumed for heating the water can then be modeled.

Although the maximum and minimum heating powers of the gas water heater (19.2 and 7 kW, respectively) and the maximum gas flow (2.3 m^3) are specified in the supplier manual, the minimum gas flow is unknown and should be determined, by using the following expression in which 7 kW is the minimum heating power, 0.8404 kg/m^3 and 45.1 MJ/kg the natural gas specific weight and lower heating value (LHV) [15], respectively:

$$\frac{7\ \mathrm{kW}}{0.8404\ \mathrm{kg/m^3} \times 45.1\ \mathrm{MJ/kg} \times 10^3\ \mathrm{kJ/MJ} \times \frac{1}{3600}\ \mathrm{h/s} \times 1\ \mathrm{kWs/kJ}} = 0.66\ \mathrm{m^3/h}$$

Regarding the water flow of the water that feeds the machines, a 4.3 L/min value was regulated, which is the minimum experimental flow able to activate the water heater.

The heat losses along the pipe between the water heater and the water can be quantified as follows:

In [16], this phenomenon is described and Eq. (1) is given to determine the heat loss (q_p), depending on the length, diameter and material of the pipe. Such equation gives a linear approximation of the heat decay, which is an approximation. The air temperature surrounding the pipe (T2) was also considered as the average of the registered temperature in the kitchen, which is another approximation undertaken in this experiment.

$$q_p = \frac{2\pi k_p L_p (T_1 - T_2)}{ln\left(\frac{D_o}{D_i}\right)} \quad [\mathrm{kJ/h}] \qquad (1)$$

In the experiment, the material of the pipe is a non insulated polyvinyl chloride (PVC) and the parameters values are [17]: Kp = 0.511 kJ/(m.^{o}C.h) (thermal conductivity), Lp = 4 m (pipe length), Do = 0.0419 m (outside diameter), Di = 0.0329 m (inside diameter), T1 = 70^{o}C (for test A and B) and 45^{o}C (for test B) (water temperature in the water heater), T2 = 25^{o}C (air temperature).

The rate of the temperature drop ($\Delta T/dt$) is given by Eq. (3) where Cp Eq. (2) is the mass thermal capacity of the water, ∂Q = q_p/dt and m is the mass of the water. Cp values for the experimental temperatures are [18]: 4.179 (25^oC = 298.15K), 4.185 (45^oC = 282.15K) and 4.193 (70^oC = 343.15K) kJ/(kg.K). The water mass is given by m = V× ρ (kg, where ρ = 1 kg/L).

$$C_p = \frac{1}{m}\frac{\partial Q}{dT}\ [\mathrm{kJ/kg.K}] \tag{2}$$

Knowing that ∂Q is obtained by q_p, the rate of temperature drop is now obtained in Eq. (3):

$$\frac{\Delta T}{dt} = \frac{q_p \times 60^{-1}\mathrm{h/min}}{m \times C_p}\ [\mathrm{K/min}] \tag{3}$$

$T_1 = 70^oC$, $T2 = 25^oC$: dt = 19min; $\Delta T/dt = 2.36^oC/min$

$T_1 = 45^oC$, $T2 = 25^oC$: dt = 13min; $\Delta T/dt = 2.28^oC/min$

This means that, for simulation A, if there is an interval between two gas consumptions of more than 19 min, the water in the pipe (and that is about to be consumed) is already at the air temperature of 25^oC. For simulations B and C, that period is 13 min. After these periods, the water heater only has an effect in the temperature of the consumed water if the water consumption lasts for enough time so that all the remaining water in the pipe is consumed and the current heated water crossed the all pipe length. This period is calculated by dividing the volume of the pipe by the water flow – the regulated water flow is of 4.3 L/min:

$$\text{Time for the water to cross the pipe} == \frac{\pi \times \left(\frac{0.0329\ \mathrm{m}}{2}\right)^2 \times 4\ \mathrm{m}}{4.3\ \mathrm{L/min} \times 10^{-3}\ \mathrm{m^3/L} \times 60^{-1}\ \mathrm{min/s}} = 47\ \mathrm{s}$$

With the above presented results, the efficiency of the water heating as a mean to provide heated water to both appliances can now be modeled dynamically at each moment.

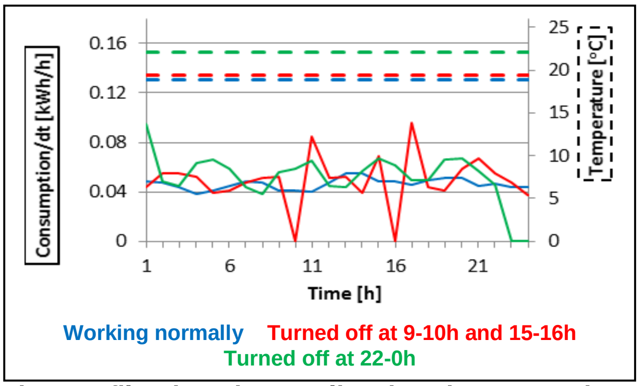
A particular feature of the experiment that was undertaken regards the initial water intake. Instead of simply turning on the washer and the dishwasher, hot water was consumed before each tested program so that the feeding water could be at a high temperature at the entrance of the appliance. This assumes, however, that this water that is used 47 s before the program is not wasted. Evidently, this is an assumption that is not realistic for each washing program that a family may use but this was the way to feed the appliance with water at the desired temperature, instead than feeding with water at the room temperature that was retained in the pipe.

Results and discussion

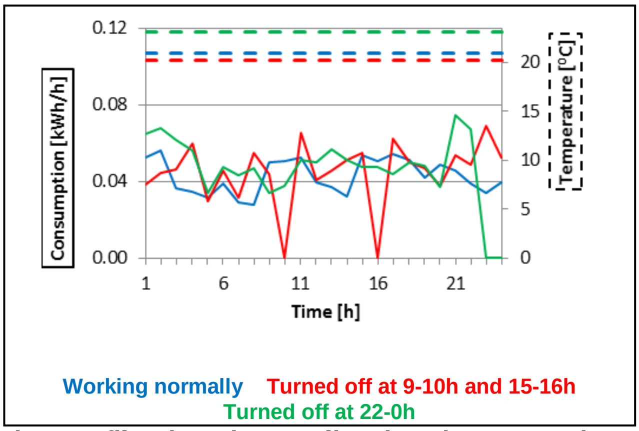
This point is divided in the analysis of results concerning the experiments in refrigerators and then concerning the washer and dishwasher. The results cover not only the energy impact but also the costs, which were calculated according to the tariffs available for one Portuguese utility [19]. Costs from the use of gas are also addressed for the analysis in the tests performed in the washer and dishwasher.

Refrigerators

The simulations undertaken for the two refrigerators show different consumption profiles in the different scenarios, as it can be perceived in the following Figures. The overall consumption results are expressed in the following Table, as well as the CO_2 emissions of each one.



Electricity consumption profiles (continuous lines) and average air temperatures (dashed lines) for the refrigerator INDESIT R 18, working in the three different schedules.



Electricity consumption profiles (continuous lines) and average air temperatures (dashed lines) for the refrigerator BOSCH KGN46A03, working in the three different schedules.

As previously mentioned, the consumption in scenarios (ii) and (iii) suffered a correction in order to mitigate the effect of the outside temperature and so the measured consumptions were corrected at the temperature registered in (i).

Overall daily consumptions and costs concerning each measured scenario for the tested refrigerators at temperature of (i).

	INDESIT			**BOSH**		
	(i)	**(ii)**	**(iii)**	**(i)**	**(ii)**	**(iii)**
Consumptions and costs						
kWh	1.115	1.177	1.189	1.028	1.113	1.075
kgoe	0.096	0.101	0.102	0.088	0.096	0.092
$kgCO_2e$	0.210	0.221	0.223	0.192	0.210	0.201
€	0.124	0.130	0.131	0.115	0.123	0.118
Balance relatively to scenario (i)						
Δ kWh	-	0.062	0.074	-	0.085	0.047
Δ kgoe	-	0.005	0.006	-	0.008	0.004
Δ $kgCO_2e$	-	0.011	0.013	-	0.018	0.009
Δ €	-	0.006	0.007	-	0.017	0.003

The following results can be stressed:

a) After a perturbation, the refrigerator increases the consumption and stabilizes. Such can be noticed in scenario (iii).

- Reckoning the refrigerator INDESIT, the consumption stabilizes after 1 h, maintaining a higher amplitude than in (i)
- Concerning the refrigerator BOSCH, the consumption stabilizes after 5 h, maintaining roughly the same amplitude as in (i).

b) The refrigerator INDESIT has a consumption while working normally – (i) – with lower amplitudes than the BOSCH.

c) Scenarios (ii) and (iii) have an associated higher consumption than in (i), corresponding to different values in each refrigerator, proportional to the associated environmental impact.

- The consumption registered in (ii) is higher than in (i), concerning the refrigerator INDESIT and BOSCH, by 5.6 and 9.9%, respectively.
- The consumptions registered in (iii) relatively to the refrigerators INDESIT and BOSCH are, respectively, 6.6 and 4.6% higher than in (i).

d) The costs differ between the refrigerators within the same scenario.

- Concerning scenario (ii), the costs rise 4.8% in the refrigerator INDESIT but, for the refrigerator BOSCH, the costs increase 7.0%.
- Regarding scenario (iii), the costs increase 5.6% in the refrigerator INDESIT and 2.6% in the refrigerator BOSCH.

As previously mentioned, the switch off periods covered the peak periods which are usually higher priced and so the costs regarded to the different tariff schemes were also analyzed. The costs that are shown above regard the average costs across the different tariffs and the detailed costs for each are not depicted in this paper because despite the tariff, the costs increased from scenario (i) to (ii) and from scenario (ii) to (iii).

Firstly, one must keep in mind that the temperature measurements were not the most accurate ones but the important factor is the temperature variation, which is trusted to be accurately achieved. Also, though considering that the using habits of the refrigerators kept constant in each simulated period, this is a point that is impossible to be precisely controlled under an *in situ* experiment. Furthermore, one does not know the performances of the engine and the compressor, which are trusted to be the main influent factors in the consumption and in the performance losses during the “on-off” cycle [12].

The operating processes differ in the two refrigerators. In fact, the refrigerator BOSCH shows higher consumption amplitudes and longer shut-down periods, and the INDESIT has a flatter profile, with shorter shut-down periods. The BOSCH is a combined refrigerator, with a power of 370 W, contrasting with the 150 W of the INDESIT, what means a higher consumption, even though it has a higher energetic certification. The dimensioning of the capacity of the refrigerator according to the dwelling’s needs is an important factor that must be consider together with the energetic label.

The usage – concerning also the induced working periods – influences the consumption profiles. In fact, the refrigerator INDESIT has a high usage during the day at lunch time and the BOSCH has generally a high usage at lunch and even higher during dinner time. The effects of such differences are explained, as follows.

Concerning the refrigerator INDESIT, the shut-down periods in scenario (ii) occurred during the day, when the probability of being used and the room temperature were higher, and with intervals of 5 h, which may not have given enough time to remove the extra heat that entered during the shut-down period. Such contrasts with scenario (iii), in which the probability of being used during, and after, the shut-down period is lower, which did not require such a high effort of the refrigerator to extract the accumulated heat during that period. Indeed, the high consumptions after the shut-down periods were

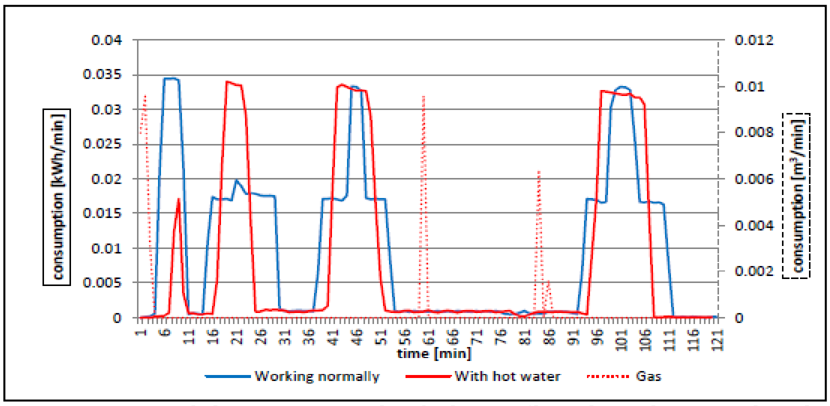
52.5% higher in scenario (ii) than in scenario (iii). This is justified by the usage, which is more intensive during the shutdown period in (ii).I Otherwise, a higher consumption peak after a shutdown period of 2 h (scenario (iii)) would be expected to be higher than in the 1 h period (scenario (ii)).

Concerning the refrigerator BOSCH, the consumption profile in (i) evidences the occurrence of periodical peaks which tend to be intercalated with the ones in (iii). This may be explained by the fact of the turn off period in (iii) being at the arising of a new peak, which implies a delay in that peak and, as well, an increase afterwards, affecting the remaining peak periods by also delaying them. As for the highest peak noticed in (iii) which occurs before the shutdown period, it may have not been a consequence of a different usage but, instead, due to the temperature increase and the fact that this period corresponds to the normal intensive usage period. Such does not happen in (i) because the consumption peak tends to be earlier. The high consumptions after the shut-down periods were 2.3% lower in scenario (ii) than in (iii), which evidences a higher need to extract the heat that got inside during the longer continuous turn-off period in (iii).

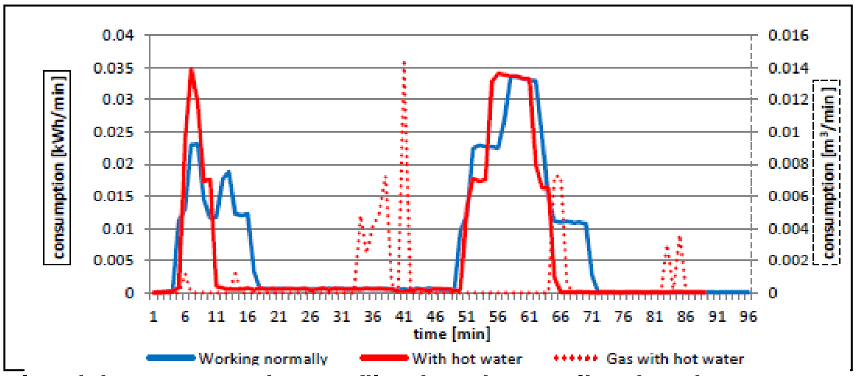
The approach that led to these results must be taken rather cautiously. The experiments were performed under some (and fair) considerations on the environments in which the two different refrigerators are placed. Surely, deviations have occurred in the usage that were not perceptive, but that is a feature of a real usage, with no exact routines by the users. Nonetheless, the relation was established concerning the induced shut-down of a refrigerator in two different schedules: an increase in the accumulated consumption at the end of the day and, furthermore, a costs increase, depending on the usage, on the refrigerator type and on the tariff. Concluding, the forcing shut-down of a refrigerator may contribute to reduce the peak loads but at the expense of higher energy consumption and clients costs. Thus, this measure does not lead to better environmental or monetary scenarios.

Dishwasher and clothes washing machines

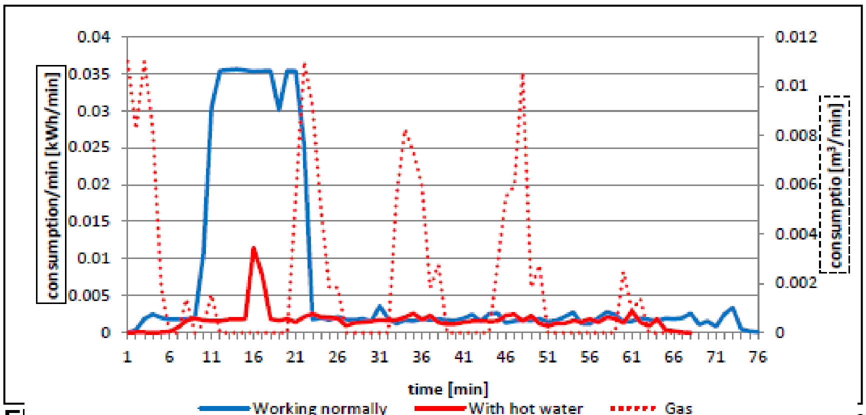
For the sake of simplification, the programs that were defined for the washer and dishwasher are referred as follows: A – dishwashing machine, working in an intensive program at 70^{o}C; B – dishwashing machine, working in an auto program at -60^{o}C; C – washing machine, working in an intensive program at 40^{o}C. The figures and table below provide the analysis of the three programs and the comparison between the normal usage (scenario (i)) and with the operation with the water feed through the hot water pipe (scenario (ii)).



Average electricity consumption/min profiles (continuous lines) and gas consumption (dashed lines) for the dishwashing machine, working in the program at 70^{o}C.



Electricity consumption profiles (continuous lines) and gas consumption (dashed lines) for the dishwashing machine, working in the automatic program at 45-65°C



Electricity consumption profiles (continuous lines) and gas consumption (dashed line) for the washing machine, working in the 40°C program.

The higher consumption in program A, when comparing with B, in scenario (i), is due to the higher water temperature for that program (70°C vs. 60°C). Once it was not possible to measure the heated water in program A, as the water flow was insufficient to activate the gas water heater (therefore, the periods in which the dishwashing machine consumed water were not measured), one could not determine the heated water in scenario (i) and, thereby, the potential scenario (iii).

As said in the Experimental section, program A operates with low water flows and so most of that water was not sufficient to activate the gas water heater. Therefore, this scenario is poorly fitted to analyze the effect from the usage of a gas water heater for heating the feeding water. This is the reason why another program with higher water demand, program B, was tested in the dishwasher experiment.

Concerning programs B and C, it is then assumed that all the used water activated the gas water heater. The average temperature of the feeding water at the entrance of the machine is 39.7 and 37.1°C, respectively, which means that the machine had to heat the water by an average of 21.3°C and 2.9°C, respectively. This reflects the inefficiency of this experimental methodology, a consequence of heat loss across the pipe length. Further, the primary energy that is consumed in scenario (i) rises 2 and 18%, respectively for programs B and C, as a consequence of of natural gas consumption. Concerning program A, the consumption of primary energy decreases 6%. The corresponding lowering in electricity consumption is, respectively for programs A, B and C, 17.9, 21.9 and 77.4%.

As far as the costs are concerned, scenario (i) corresponds, averagely, to an associated increase of 2.1, 2.3 and 82.6% for programs A, B and C, respectively.

Finally, the CO_2 emissions are characterized, respectively for programs B and C, by an increase of 0.06 and 0.15 kgCO_2e. Concerning program A, there is no variation.

Overall consumption and cost per cycle, concerning each measured scenario. Costs are averaged for all calculated tariffs[a].

	A		B		C	
	(i)	**(ii)**	**(i)**	**(ii)**	**(i)**	**(ii)**
Electricity	1.17 kWh	0.96 kWh	0.64 kWh	0.50 kWh	0.53 kWh	0.12 kWh
	0.34 kgoe	0.28 kgoe	0.19 kgoe	0.15 kgoe	0.11 kgoe	0.03 kgoe
	0.55 $kgCO_2e$	0.45 $kgCO_2e$	0.30 $kgCO_2e$	0.24 $kgCO_2e$	0.25 $kgCO_2e$	0.06 $kgCO_2e$
	0.143 €	0.115 €	0.077 €	0.062 €	0.063 €	0.017 €
Gas	-	0.04 m^3	-	0.05 m^3	-	0.14 m^3
	-	0.04 kgoe	-	0.05 kgoe	-	0.13 kgoe
	-	0.10 $kgCO_2e$	-	0.12 $kgCO_2e$	-	0.34 $kgCO_2e$
	-	0.025 €	-	0.033 €	-	0.098 €
Water	12 L	12 L	17 L	17 L	50 L	50 L
Water in heater	-	- [a]	-	17 L	-	50 L
Water temperature	25°C	- [a]	25°C	39.7°C	25°C	37.1°C
Balances (i) - (ii)	- 0.21 kWh		- 0.14 kWh		- 0.41 kWh	
	-0.02 kgoe		+ 0.01 kgoe		+ 0.02 kgoe	
	+ 0.04 m^3		+ 0.05 m^3		+ 0.14 m^3	
	+ 0.02 €		+ 0.05 €		+ 0.05 €	
	0.0 $kgCO_2e$		+ 0.06 $kgCO_2e$		+ 0.15 $kgCO_2e$	
Electricity spent in water heating	-	-	0.33 kWh	0.17 kWh	0.47 kWh	0.06 kWh
	-	-	0.07 kgoe	0.04 kgoe	0.10 kgoe	0.01 kgoe
	-	-	0.16 $kgCO_2e$	0.08 $kgCO_2e$	0.22 $kgCO_2e$	0.03 $kgCO_2e$
	-	-	(52%)		(89%)	

[a] Could not be measured

Conclusions

This work comprises an experimental analysis of the performance of two refrigerators, one dishwasher and one clothes washing machines, upon operational strategies being undertaken. Both energy consumption and costs were analyzed and the general conclusions follow.

Concerning the refrigerator, the tests showed that a forced turn-off period results in a higher daily accumulated consumption, as well as higher costs, which demystifies the belief sustained in [6]. The consumption increase depends on the working schedule and on the refrigerator type, reaching values between 4.6% and 9.9%. Furthermore, the costs do not increase at the same rate as the consumption, being this within 2.6% and 7.0%. Nonetheless, costs increase independently from the tariff in both scenarios (ii) and (iii).

The applied methodology had the purpose of testing real scenarios, leading to realistic results. However, more detailed experiences must be done in order to analyze the real effects of an induced shut-down on the functioning of the refrigerator since it may induce a deregulation of the engine and compressor and may cause a temperature drop which may affect the stored food. The tests in this work concerned two different refrigerators in two distinct environments, what constitutes a limited sample. Hence, further studies must be performed in order to prove irrefutably if this behavior is, or not, benefic or harmful to the refrigerator and the food, and if it implies an increase in consumption and costs.

Concerning the dishwasher and washer, the general results of the tested methodology (scenario (ii)) show, for programs B and C, worse energetic and economic scenarios than in the normal working way (scenario (i)), being a consequence of the consumption of natural gas for heating the feeding water. As for program A, the CO_2 emissions maintain but the costs and the primary energy consumption decrease slightly, the main reason being that the electricity consumption in this program is higher and the gas consumption is lower than in the other tested programs, which means that the gas consumption does not have the same impact as in the other two tested programs. Hence, for the dishwashing machine working in program auto, at 45-65^{o}C, the costs increase 23.4%, and, in the washing machine working in program at 40^{o}C, they rise 82.5%.

The CO_2 emissions raise until 60%, meaning that this methodology is worse environmentally and economically. The temperature loss in the water pipe between periods with no water consumption contributed to the loss of efficiency in the operation process. Since the electricity that was spent in heating the water by the appliances was determined, one can now dissert on the existence of a scenario that can achieve the same performance as these experiments, on what the temperature of the feeding water is concerned, but with a lower impact than natural gas combustion. Acknowledging such a system as *e.g.* a solar collector system for water heating, this could induce a reduction of electricity consumption during the washing cycles of 52% (0.33 kWh and 0.16 kgCO_2e) and 89% (0.47 kWh and 0.22 kgCO_2e), for the dishwashing and the washing machines, respectively.

This work succeeded in the experiment in four different appliances upon the application of consumption strategies that differ from their common operation. However, a more controlled environment should be set so that a proper quantification of the energy and costs balance between the scenarios can be undertaken. Experiments that tackle strategies such as the ones that were presented in this work are encouraged as these strategies can reveal lower energy and economic performances than the normal operating scenarios.

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Innovative add-on to the home energy management system for residential swimming pool energy efficiency

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Abstract

Most of the existing private swimming pools were built before the present trend of energy efficiency had come into mainstream, many times with inefficient hydraulic circuits. This is an important factor in the fact that swimming pool energy consumption represents a significant share in the overall consumption of houses that have pools, and very frequently is considerably higher than necessary.

The energy consumers in a swimming pool are filtration, filter backwashing, lighting, water features, cleaners, automatic chemical balance equipments and heating systems.

Energy consumption of swimming pools became evident in developed countries where a large number of pools are installed. Hence a number of measures, such as scheduling, efficient motors, multiple and variable speed motors, and improved pool building regulations were introduced and on some countries were made mandatory.

In Portugal most pools are not heated, and hence the main pool energy consumption is the filtration. To reduce the energy consumption in filtration scheduling can be utilized without changes on the hydraulic circuit. Replacing specific equipments, such as filters, pumps and motors is normally applied only when the concerned equipments fail. And changes on the hydraulic layout of the system, such as pipe diameter and reduction of localized pressures losses, are generally only economic in the construction phase.

One of the biggest and easiest energy savings potential is related with scheduling of the filtration system. An innovative control of swimming pool equipment has been designed, that uses information gathered though weather information services to optimize the pool energy consumption, allowing very significant energy savings.

The system will be an add-on to the home energy management system, and will provide, through smart phone, tablet and PC, information to the owner about the pool energy consumption, forecasting and alarms. The user will also be able to interact with the system to optimize savings.

Typical residential swimming pool energy consumption

Most of the existing private swimming pools were built before the present trend of energy efficiency had come into mainstream.

In countries with less developed swimming pool markets the construction and equipment standards are not sufficient to result in energy efficient pool construction. As a result many pools were built in an energy inefficient layout, in particular with inefficient hydraulic circuits and equipments.

Also sometimes there is inadequate knowledge on how to maintain a pool lacking, and pool maintenance is frequently subcontracted at a fixed rate. This results frequently in exaggerated preventive practices of filtration that excessively safeguard the pool water quality, at the expense of waste of energy.

This is an important factor in the fact that swimming pool energy consumption represents a significant share in the overall consumption of houses that have pools, and is frequently considerably higher than necessary.

Energy consumption of swimming pools became evident in countries with higher living standard where a large number of pools are installed. Hence in regions like for example the United States of America, Australia and to a lesser extent also in Europe, a number of measures, such as scheduling, efficient motors, multiple and variable speed motors, and improved pool building regulations are introduced and some of them made mandatory. [1][2][3]

The main energy consumers in residential swimming pools are identified in the following table.

Table 1: Main energy consumers in residential swimming pools

Consumer	Description
Lighting	In most pools this is a reduced yearly energy usage due to the relatively low number of hours of utilization per year.
Water features and SPAS	Typically a low number of hours per year of utilization. In the case of high power booster pumps usage then the energy consumption will be more significant.
Filtration pump work	This is typically the majority of the energy consumption of unheated pools. Typically consisting of a large number of hours per day of pumping.
Heating	This can be done through heat pump, solar thermal and boilers. In a heated pool will frequently represent the major energy consumption, depending on the heating season duration.
Cleaning equipments, water quality equipments and filter cleaning	This includes vacuum cleaners of pool bottom and walls, which may be driven by the filtration pump on suction or pressure side, or may be a standalone electric system. The operation may be done manually, of by an automatic equipment that roams in the pool for a determinate period. The pressure side cleaners using booster pumps are more energy intensive than the other alternatives. Other, relatively small, energy consumers are the water chemical balance automatic equipments. These include chlorinators, PH balancing and other chemical dispensers. The filter backwashing in the case of sand, diatomaceous earth and zeolite filters also consumes energy, although the yearly amount is quite small when compared for example with the regular filtration energy usage.

Potential for energy efficiency

Lighting

There is potential for energy efficiency, but the relatively low consumption and low number of yearly operation hours results in a moderate improvement potential.

Water features and SPAS

The potential of saving is very site and behavior specific. The first thing to do is to minimize the yearly number of hours of usage of these features. If the total yearly usage time is small then the driver for equipment changes for energy efficiency will be small.

Heating

Depending on the present setup and yearly heating utilization there may be significant energy efficiency potential. This can be addressed namely through pool covers, renewable energy using solar thermal, or efficient heating systems such as heat pumps.

Cleaning equipments, water quality equipments and filter cleaning

Some savings can be achieved changing the vacuum cleaner, in particular if the present cleaner uses a booster pump. A standalone electric cleaner may be the most energy efficient, although is a comparatively costly investment.

The automatic water balance equipments represent an overall low consumption.

Filter backwashing based on pressure reading rather than scheduling can eventually reduce this consumption.

Filtration pump

To reduce the energy consumption in filtration several options are available, which are described in the following table.

Table 2: Possibilities for filtration pump energy consumption reduction

Area	Description
Duration and moment of filtration	Changes to the duration and moment of pumping can be utilized without changes on the hydraulic circuit. Some studies, in particular one in which about 100 pools were monitored during 2 years in Florida [4], challenge some concepts that are generally considered as good practices. For example the necessity of a minimum of one turnover per day, the need of 6-8h of pumping per day, the role of pumping in chemical dissemination through the pool, among others.
Reduce pressure drop by changing filters	Replacing filters by larger filters with lower pressure drop can sometimes be done, depending on the pump curve and the present operation point. For the same flow rate there would be a decreased pressure drop across the filter which would result in lower energy consumption. But this may result, in a single speed pump, in a higher flow rate, and the overall consumption may be higher as a result (see Figure 1). So this may result in higher energy consumption without changing the pump. Hence a pump change may be also necessary, which will result in an overall significant investment. As a result this will normally not be done except in new pools or when involved components fail. To adopt a filter with higher pressure drop may result in ineffective filtration, assuming the present filter is appropriate for the pool needs.
Replace pumps and motors	This is normally applied only when the concerned equipments fail. Hence measures such as efficient motors, multiple and variable speed pumps, apply mostly to pump replacement and new pools.
Changes to the hydraulic setup	Significant changes to the hydraulic layout of the system, such as pipe diameter and reduction of localized pressures losses, are generally only economic in the construction phase.

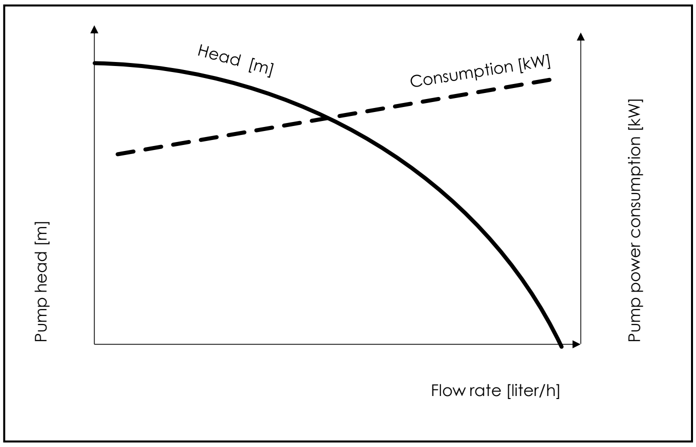

Figure 1: Sample pump curves

The case of Portugal

In Portugal most pools are not heated, and hence the main pool energy consumption is the filtration pump.

According to our initial research it is not infrequent that pool pumps are run by a factor of 2 or more above the necessary to maintain water quality, being sometimes the larger isolated electricity consumer in a household [4] [5] [6].

Pool filtration and water quality

Main functions of pool filtration

The filtration pump activation has the following main effects on the pool:

- Collects debris suspended in the water near the surface (contaminants less dense that water or that fell in the water recently)
- Collects in a very limited way sunken debris – the suction of water through the bottom drain does not collect the majority of the debris that were already deposited in the bottom of the pool (which is what happens to the debris that are not on the water surface in case there is no significant agitation of the water (like swimmers).
- During or shortly after a scrubbing of the walls or floor collects the suspended debris.
- During vacuum cleaning with equipments that use the pool pump as a driver it collects the debris through the cleaning equipment.
- In case there is automatic chemical balance equipment (like chlorinators, PH balance, etc) that depend on the pool pump to operate efficiently (typically these are placed in the filtration circuit piping) the activation of the pump is necessary with a sufficient flow and duration that allow appropriate operation.

If an adequate level of filtration is ensured, additional running of the pump will not result in perceptible water quality improvement and is not the main factor to reduce the formation of algae - chemical treatment and scrubbing are more important than filtration. The algae formation occurs even if the filtration is run 24 hours per day. The way to reduce algae formation is to maintain the chemical parameters of the water in the correct range and perform physical cleaning (vacuum cleaning, scrubbing of floor and walls). [4] [6]

Pool contaminants and relation with climate

The following table identifies the most relevant pool contaminants and their relation with the weather conditions.

Table 3: Pool contaminants and relation with climate

Contaminant	Relation with climate
Swimmers – introduce lotions, perfumes, dead cells, detergents, urine, sweat, transported dirt in the feet, etc	Higher pool occupation coincides with higher ambient temperatures and solar radiation availability. In cold weather there are generally no swimmers in unheated pools.
Debris from natural surroundings – tree leaves, pollens, insects, contaminants resulting from storms, dust, etc.	Depends mostly on natural surroundings and the distribution along the year is variable. The usage of a pool cover minimizes these contaminants.
Wear of the pool walls and bottom.	Some pool materials result in a mineral contamination of the water that affects the PH.
Algae and bacteria growth	Depends mostly on 4 factors: temperature, availability of solar radiation, already existing base population of algae and bacteria and the composition of the water. Rapid growth can occur in warm months.

Optimized filtration by add-on to energy management system

The optimization of the pool consumption described in this paper is designed as an add-on to an existing energy management system. The already existing energy management system should have the ability of collecting energy consumption data, store it and make it available to the home owner. Furthermore it should have the capability of switching on and off electrical loads. The user interface of such existing energy management system should ideally be through smart phone, tablet and PC and have alarm, report and user interaction capabilities. For this, data storage in a remote server and communications are required.

As an add-on to such system, the pool consumption optimization will run as a process in the same hardware of the energy management system, and will have access to the capabilities already built in it, described above. Additionally the necessary modifications is the existing electrical connections to the swimming pool pump have to be made to allow switching on and off by the energy management system.

As seen in previous sections one of the biggest and easiest energy savings potential in existing residential pools is related with the amount and the moment of pumping of the filtration system, and there is scope for significant energy savings to be provided. Following the information of previous sections a baseline for pump running hours per day can be calculated based on these factors:

- ambient temperature (or as alternative, water temperature)
- solar irradiation
- if pool is covered or not
- pool occupation/usage

Using the mentioned resources of the energy management system, the add-on will have access to the actual pool energy consumption. It will also have the possibility of acquiring weather data from a central server or weather services. And will be able to share the user interface for data reporting.

And will also, through the same interface, be able to interact with the owner to receive feedback and configuration by the home owner, in order to optimize water quality and savings. For example the user can inform that the pool will be unused for the weekend and it is covered. Or, on the other hand, that additional cleaning is needed in one particular day, for example when inviting several friends. Specific instructions can trigger special pumping modes cases, for example, in the event of algae boom extra pumping will be needed for some time during and after the chemical and physical treatments.

The specific pumping needs are very site specific [4] [7], and hence a number of calibrations for each pool have to be made based on several factors, which will be done by collecting information from the user on an initial setup, for example:

- Pool volume
- Pump capacity
- Piping diameter
- Existing filter
- Natural surroundings
- Pool materials
- Pool usage

Then, based on variables and feedbacks mentioned the pool energy efficiency add-on will calculate an optimum running time for the pump each day. And will also determine in which times of the day these energy consumptions will take place, taking in consideration the electricity cost along the day, to ensure minimal energy costs

Example

Considering one real case of a 92 m^3, uncovered swimming pool in the region of Évora, with a 1,3 kW single speed pump that provides around 21 m^3/h, it would take about 4,4 hours to make one full pool volume turnover.

Let us assume a not uncommon scenario in Portugal of a timed circulation pump, that is adjusted twice a year. In the winter months runs 4 hours per day, 2,5 of which in the low electricity tariff. In June the timer is adjusted to Summer mode and remains there for 5 months, running 7 hours per day, 3 of which in the low tariff.

Considering 0,097 €/kWh in the low tariff (taxes included) and 0,185 €/kWh in the rest of the day, a pumping cost of 349 €/year is found.

The pool efficiency add-on would calculate with daily temperatures and solar irradiation a necessary pumping. Figure 2 presents a sample result for Évora, for pool similar to the one used in this example. Of course the actual needs depend on several factors and specific calibration will be needed.

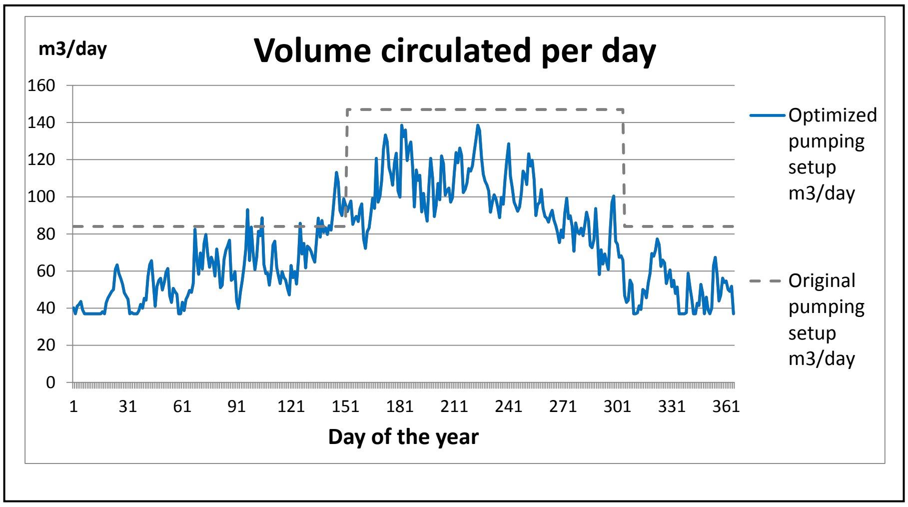

Figure 2: Sample of yearly original and optimized pumping profile for uncovered pool

This optimized profile results in 50% of previous turnover in the coldest days of the year and a very significant reduction in many of the days previously fitted in the general “Summer setup” season. This is made possible by the effortless daily adjustment of the pumping needs, instead of adopting an high, preventive, pumping profile because there is no practical means of making constant changes. On the other hand by scheduling the energy consumption mainly to low tariff periods maximum savings are possible.

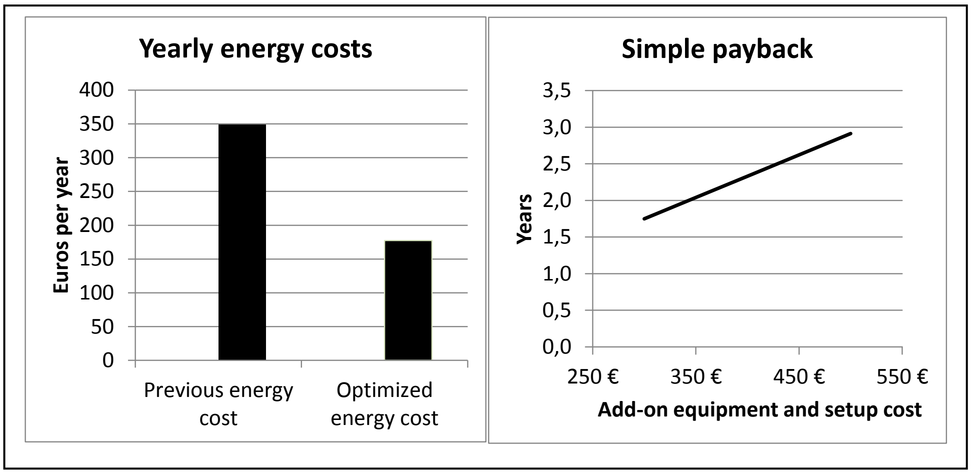

Figure 3: Yearly energy savings and simple system payback

The specific pumping needs are very site specific [4] [8], and hence a number of calibrations for each pool have to be made based on several factors, including:

- Pool volume
- Pump capacity
- Piping diameter
- Existing filter
- Natural surroundings
- Pool materials
- Pool usage

One of the advantages of this approach to energy efficiency is that it can be applied to most existing pools with minimum intervention in the present layout and without changing equipments or piping.

Conclusions

Swimming pool energy consumption represents a significant share in the overall consumption of houses that have pools, and is frequently considerably higher than necessary.

One of the biggest and easiest energy savings potential in existing residential pools is related with the amount and the moment of pumping of the filtration system, and there is scope for large energy savings to be provided by a pool filtration control that correlates weather data, pool occupation and pool cover utilization.

An innovative control of swimming pool equipment has been designed that uses this information, including data collected through weather services to optimize the pool energy consumption, allowing very significant energy savings.

The system will be an add-on to the home energy management system, and will provide, through smart phone, tablet and PC, information to the owner about the pool energy consumption, forecasting and alarms. The user will also be able to interact with the system to optimize savings.

One of the advantages of this approach to energy efficiency is that it can be applied to most existing pools with minimum intervention in the present layout and without changing equipments or piping.

Hence it can be easily fitted to existing pools, with low initial cost.

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Are German consumers using their dishwashers in an energy-efficient way? An online study of German households.

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Abstract

The implementation of the *Energy transition* in Germany constitutes a big challenge over the next few years. Within the changeover, 80-95% of greenhouse gas emissions should be saved up to 2050, for example, by increasing the usage of regenerative energy. However, end-users especially have to bear the costs of changing fossil fuels to renewable energy resources.

As a consequence, certain German politicians propose free energy consulting services for all private households. Nevertheless, an assessment of concrete usage patterns and reasons for certain consumer habits for every kind of residential appliance is essential for more detailed energy-saving advice particularly about using household appliances. Therefore, this study aims to investigate the usage of automatic dishwashers in detail by investigating the programme availability and choice, and the pretreatment of dishes. First and foremost, consumers' experiences of using various dishwashing programmes should provide information about improving the potential of optimising programmes technically, and also change the usage behaviour towards a more energy-efficient way of operating automatic dishwashers.

Data from 4002 German households were collected within the framework of an online study in December 2011. The participating households were selected by the representative distribution of age groups and the size of households in Germany. A standardised questionnaire about the dishwashers used and the way of operating the appliances were filled out via internet.

The results show a great variety of consumer habits. Nevertheless, the analysis also shows that 50% of households which have an automatic or eco-/label programme used it often or always, whereas the intensive programme is used by only 15%. In spite of the high share of eco-/label and automatic programme users, 30% indicated pre-rinsing or washing up their pots and pans by hand, which is also an energy consuming process. For those reasons, energy saving potentials have to be identified for the whole washing-up procedure.

Introduction

Within the framework of the so-called *Energy transition*, an increasing usage of renewable resources, such as wind, solar power or photo-voltaic systems, should help to decrease 80-95% of the greenhouse gas emissions in Germany up to 2050. [1] Nevertheless, end-users will have to finance the costs of the expansion of using regenerative energy. Leading German politicians are striving for the implementation of free energy consulting services for end-users. [2] Therefore, saving electricity will be a major challenge for private households over the next few decades.

In 2010 the proportion of private households measured by the end-use energy consumption amounts to 29% of the total energy consumption of Germany. [3] Of this 29%, roughly 6% [4] is consumed by using automatic dishwashers. However, the use of automatic dishwashers lowers the resource consumption in comparison to washing up the dishes by hand. [5]

The market saturation of automatic dishwashers in Germany currently amounts to 67.0%. [6] Approximately 25 million dishwashers are in use, based on about 36 million private households.

Life Cycle Assessments have shown that most of the environmental impacts within the life cycle of automatic dishwashers arise from the use phase, which presents the most consumer-relevant phase. [7]

Studies were carried out to uncover existing saving potentials to investigate the use-phase or rather the consumer habits in cleaning dishes. The dishwasher programmes used by consumers often indicate the use of normal or intensive programmes and fewer eco-/label programmes. Furthermore, only 13% of households with dishwashers load everything into the dishwasher and do not wash up any of their dishes by hand. The other users use additional water and energy by cleaning their dishes by hand, for example, under running tap water instead of using the automatic dishwasher. [8] Other studies found out that pots and pans are more often cleaned by hand than in the dishwasher. [9]

The aim of the online-study presented is to answer the question if German consumers are able to use their automatic dishwashers in an energy-efficient way. In the case of identifying inefficient habits in handling the washing of dishes in private households, energy saving potentials should be derived.

Material and Methodology

A total of 4002 private households in Germany were asked about their dish washing treatment and usage habits of their automatic dishwashers within the framework of a web-based study. The participants had to fill in an online questionnaire containing questions about different aspects relating to dishwashing in their private homes, e.g. type of dishwasher, dishwasher programmes (availability, programme choice), reasons for selecting specific programmes, and the pretreatment of their dirty dishes.

The following requirements for participation in this study were defined:

1. Households should possess and use an automatic dishwasher frequently.
2. The age of the dishwasher should not exceed 11 years (European Union energy label has to be introduced to guarantee the availability of an eco-/label programme or EN 50242 [10] programme, respectively)
3. Quotas of the first digit of the German postal code, the households' size and age groups were given according to current EUROSTAT Data. [11]

A control question ("*How often do you use your dishwasher per week?"*) was asked twice in order to obtain reliable data from the respondents. In a following step, people whose indications differed substantially were not included in the analysis. Consequently, a panel of 3836 households was taken into account in the final data analysis.

Results and Discussion

Demography of the participants

The distribution of the demographical data – gender, age groups and size of households – is presented in Table 1.

It is noticeable that the distribution of age groups and household size in the panel surveyed corresponds well with the current distribution in the German population. For that reason, the panel investigated gives a realistic reflection of the population.

Table 1: Demographical data of the respondents (n = 3836)

Demographic characteristics	**Number of respondents (%)**
Gender (n = 3836)	
Female	2036 (53.1)
Male	1800 (46.9)
Age group (n = 3836)	
20-39	1480 (38.6)
40-59	1475 (38.5)
60-74	881 (23.0)

Size of household (n = 3836)	
1 person	654 (17.0)
2 people	1477 (38.5)
3 people	804 (21.0)
4 people	630 (16.4)
5 people or more	271 (7.1)

Programme availability and choice

The most relevant impact factor on the energy consumption of automatic dishwashers is constituted by the programme selected. Therefore, a central issue within the framework of the study was the programme availability and, consequently, the programme choice consumers' made. In a first step, the respondents were asked which programmes are available on their dishwasher.

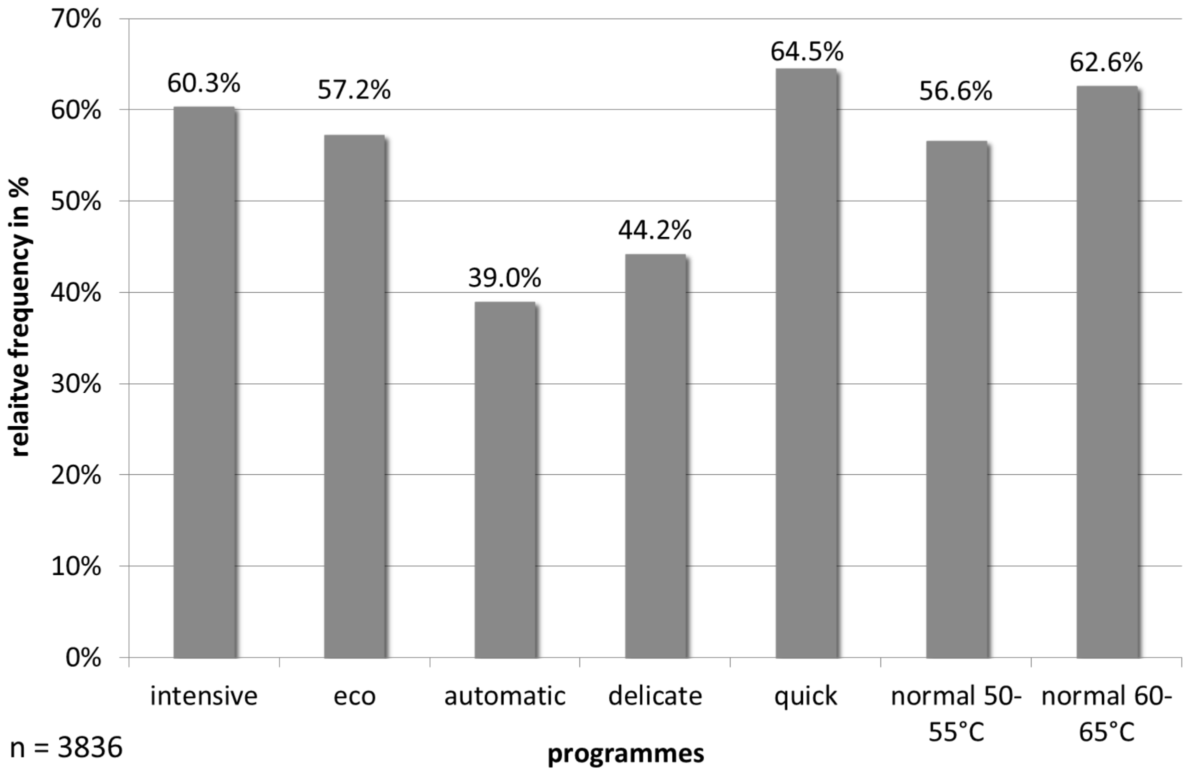

Figure 1: Available programmes of the automatic dishwashers in the participants' households (n = 3836, yes/no question for each kind of programme)

Figure 1 presents the percentages of programmes available – categorized into seven different programmes. Five of the seven programmes (intensive, eco-/label programme, quick, and both normal programmes) are available in 56.6 to 64.5% of the households questioned. The other programmes are less available. The delicate programme was indicated by 44.2% and the automatic programme by 39.0% of the respondents. However, it should be noted that the consumers themselves have decided which programme is available or not. That means there was no control of the machine types by reading a manual or asking an expert. Indeed, the low percentage of the eco-/label programme is doubtful. Relating to the requirements stated (age of the dishwasher < 11 years), the machines had to be marked with an energy label and must have had an eco-/label programme (standard test programme according to EN 50242). Reasons for this discrepancy could be inattentive consumers, on the one hand, and the programme name not being clearly identifiable or ambiguous for the user, on the other hand.

The participants were next asked which of the available programmes they frequently used. The answers should be given on an ordinal scale (never, rarely, sometimes, often, always). The results are shown in Figure 2. Roughly 50% of the households use an eco-/label, automatic or a normal 50-55°C programme often or always. Nevertheless, a considerable share of 15% of the participants chooses the intensive programme and almost 20% use the quick programme often or always. This data reveals that every programme is used on an everyday life basis by most private households. Even intensive and quick programmes are used very often by some consumers.

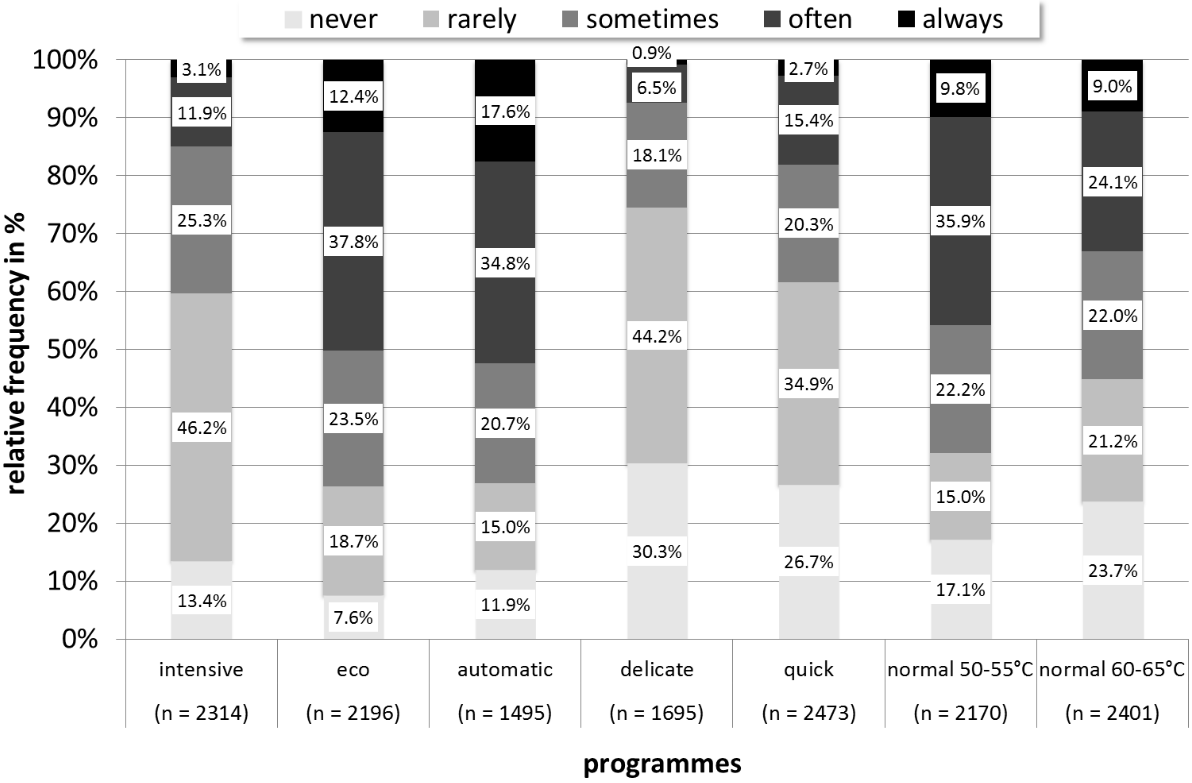

Figure 2: Frequency of use of the programmes available (*How often do you use this programme?*)

Reasons for using specific programmes

Besides the frequency of using the dishwasher programmes available, the precise reasons for the programme choice reveals tendencies of the current consumer knowledge of energy-efficient dishwashing.

Predefined statements were given to the respondents to find out why people choose their specific dishwasher programme. The respondents had to decide if they agreed or disagreed with each statement. Only households which have the programmes and additionally use the specific programme at least rarely were asked.

Over 75% of the households agree with the statement that pots and pans get clean in the intensive programme, at the same time, not even 20% of them believe that using intensive programmes lead to savings of energy and water (Figure 3). Therefore, it seems to be known that intensive programmes have high resource consumption, but nonetheless, these programmes have also a high cleaning result. Similar results were found regarding the normal 60-65°C programme. In case of a high soil level and baked-on residues e.g. on a casserole dish the intensive programme is an efficient solution to receive a satisfying cleaning result.

Relating to the eco-/label programme, the exact opposite is the case. Almost 80% of the households indicate that water and energy savings are possible by using the eco-/label programme, but only 40% think the programme is useful for cleaning heavily soiled items. The question is how consumers define a hard soil level on their dishes and if they connect energy-saving programmes or options relating to dishwashers or household appliances in general, with less efficiency. If the users do so, the function and purpose, as well as the efficiency of such energy saving programmes and options should be communicated in more detail and should be suitable to defined target groups. Nevertheless the programme choice should depend on the soil level of the item. However, for normal soiled dishes the eco programme enables us to save water and energy most.

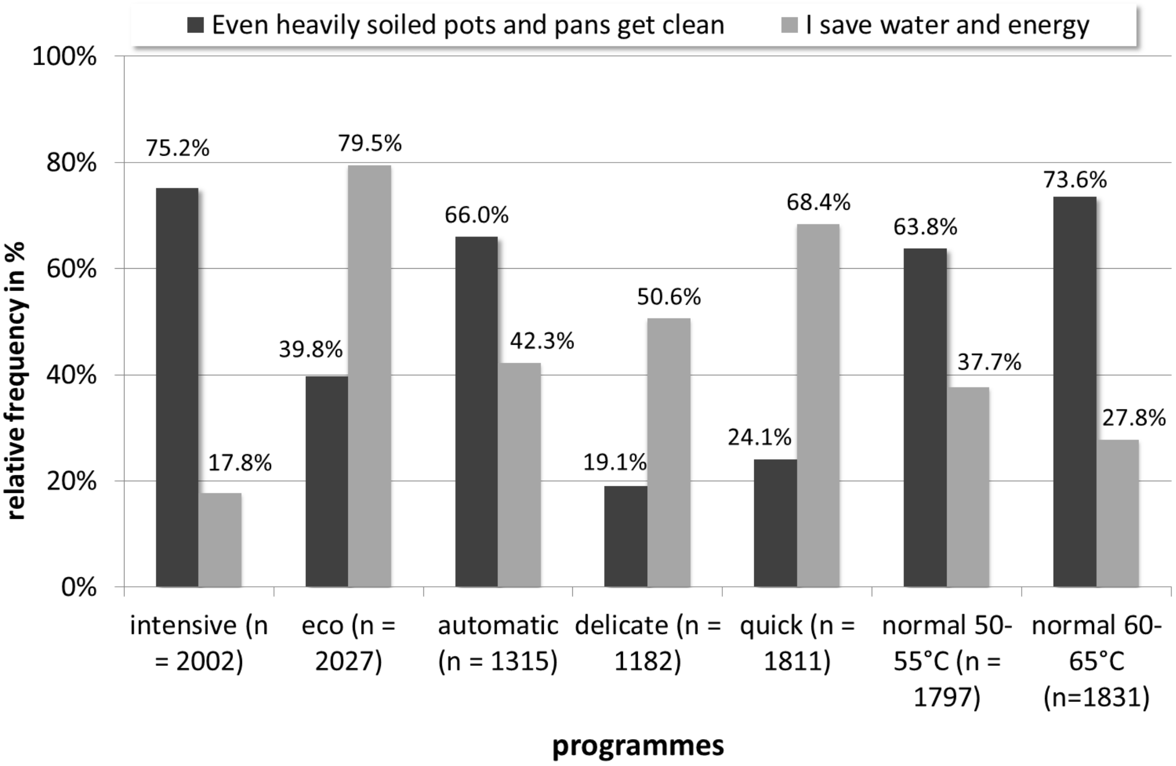

Figure 3: Consumers' opinions about choosing specific programmes – ***Do you agree with the given statements? Yes, I do.***

Pretreatment of dishes

Not only the appliance itself makes a contribution to the energy consumption of dishwashing processes in households; even the pretreatment of dishes and the additional manual washing-up raise the resource consumption of cleaning the dishes.

To take all processes of dishwashing into account, the participants were asked if and how they pretreat especially heavily soiled and huge items, such as pots and pans, in detail (Figure 4). Statements about pretreatment were given and the participants should answer on an ordinal scale (never, rarely, sometimes, often, always).

It is remarkable that 30% of all participants pre-rinse their dishes often or always. Furthermore, 30% also clean their dishes manually in most cases. That means more water and energy is consumed which cannot be neglected by a holistic approach to investigate dishwashing in private homes with automatic dishwashers.

Nevertheless, a remarkable share of 25% indicates cleaning the dishes only in the dishwasher even if the items are heavily soiled.

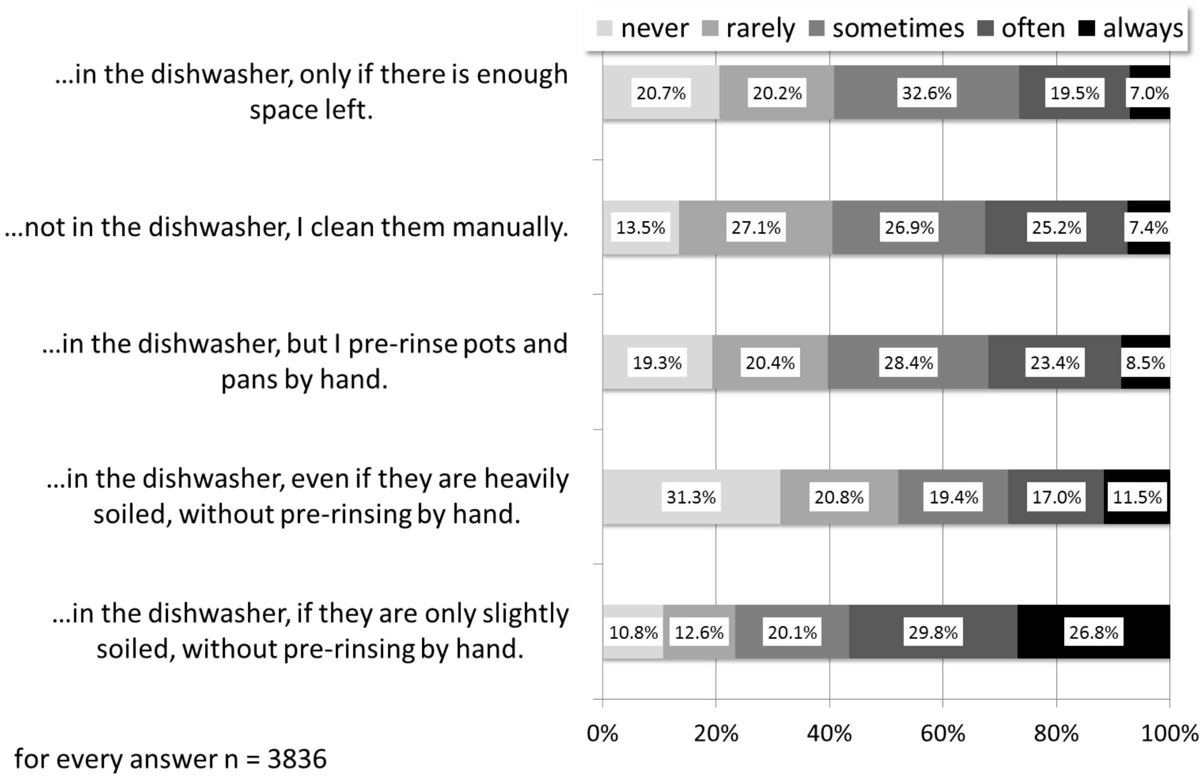

Figure 4: Way of cleaning pots and pans (*How do you clean your pots and pans?)*

Conclusion and Outlook

An energy-efficient usage of household appliances, especially automatic dishwashers, requires a large variety of actions. The replacement of old devices and the installation of a warm water supply could be notable solutions to create optimal conditions for low resource consumption of automatic dishwashers. Nevertheless, the use-phase of a dishwasher makes up the biggest part of the resource consumption. Therefore, the consumers themselves have the greatest impact on the energy consumption of dishwashers.

The results of this study have shown a broad range of consumer habits and usage patterns relating to cleaning the dishes in households with automatic dishwashers. Every partial aspect analysed has revealed a group of consumers whose dishwashing habits could be improved, for example, by knowing the programmes available in more detail or using the eco-/label programme more often. The programme names, for example, should be clearer and the consumer should know for what kind of dishes and soil levels the programmes are designed. Furthermore, the results show that energy-saving programmes are often valued as inefficient regarding the cleaning results of pots and pans. The function and purpose as well as the efficiency of such energy-saving programmes and options should be communicated in more detail and more clearly, and should be suitable to defined target groups.

In addition to the resource consumption of the dishwasher, different treatments of the dirty dishes have to be taken into consideration. Pre-rinsing or even manual cleaning of pots and pans is practiced by one third of the whole panel. Here again, consumer information about changing the habits of pre-rinsing or manual washing-up of items is necessary.

The detailed usage and, first and foremost, the reasons why consumers use their dishwashers in the way indicated is being investigated in on-going studies. These investigations will focus on the usage of eco-/label programmes and will include additional aspects, such as pre-rinsing and manual washing-up behaviour in households with automatic dishwashers.

Acknowledgements

This work was supported by Henkel AG & Co. KGaA and Miele & Cie. KG.

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Energy&Appliances 2015 project: a new approach for testing appliances with respect to end-users behaviour

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Abstract

The paper will deal with the characterization of the market of household appliances with particular attention to the role of the consumer in selecting the greatest eco-efficient products and to new requirements related to electronics.

Characteristic user profiles have been defined, based on literature data, laboratory experience and *ad hoc* investigations at national and local level with deep analysis of the main parameters such as dimensions and type of families, type of house, appliances in use, use habits, consciousness and sensitiveness about aspects concerning the environment protection and the rational use of energy, perception of the user about economic aspects, information for improving the service given by appliances.

New testing procedures have been determined and tests have been performed on "standard" appliances and they are in progress on the improved, more efficient ones. The paper will show in particular the testing results for refrigerator-freezers.

Introduction

In the framework of "Industry 2015 Energy Efficiency", funded by the Ministry of Economic Development - Area Technology B5.1 "Innovative technologies for the production of high efficiency appliances, with reduced environmental impact throughout the lifecycle in terms of reuse of materials also including the ease of assembly and disassembly", the project Energy&Appliances 2015[1] aims at creating of a family of highly innovative appliances, characterized by the use of materials and technology which so far have never been applied to the reference sector. These may greatly reduce energy consumption and environmental impact of their own, even at disposal and recycling. The main objective of the project is to develop a range of appliances within three years, characterized by a considerable reduction in consumption of energy and water, through the implementation of specific evidence. The various steps involved in the large enterprises, SMEs, research institutes, is located around the centers of Italian excellence ensuring access to skills necessary to consolidate the new solutions through research, validation, regulatory law and technological transfer.

In developing the project, across all product lines, the following main areas will be investigated:

- Innovative materials for improving energy efficiency and reducing environmental impact;
- Innovative technologies for cleaning clothes and dishes;
- Innovative technologies for the preparation and storage of food;
- Innovative Electronic Technologies (sensors, control logic, user interfaces);
- New methods for the qualification and certification of the products.

To achieve the objectives of the project, there are three main phases to be developed over the total duration: research on all macro-areas in order to demonstrate the potential applicability of the solutions through the development of prototype pre-engineered demonstrators (pre-technical,

[1] www.energyappliances2015.it

technological and economic); the final realization of demonstrators, including some most promising solutions, after verification of the technical, technological and economic aspects. The final phase involves energy impact analysis including product certification.

The EU energy label is designed to provide consumers with accurate, recognizable and comparable information on domestic household products regarding energy consumption, performance and other essential characteristics. It allows consumers to identify how energy efficient a product actually is and to assess a product's potential to reduce energy costs. The label is uniform for all products in a given category. Consumers can compare easily the characteristics of appliances in a given category such as energy or water consumption, or capacity. All the information the label contains is based on test standards prescribed in the European Legislation. The label initially classified products from A to G, A being the most efficient energy class and G the least efficient. The freshly revised European legislation introduces classes up to A+++ to adapt to technological developments and to allow further product differentiation in terms of energy efficiency.

New labels takes into account the state of art of the market, but also is more linked with user habits; this process is at different stages of implementation, depending on the different appliances. E.g., for Washing machines, the label no longer includes a washing performance class as an A class washing performance is mandatory for all washing machines with a washing efficiency class greater than 3 kg. Annual energy consumption is in kWh (no longer per cycle), and the annual energy & water consumptions, and the spin-drying efficiency class indicated on the label, are calculated on the basis of: 60°C cotton programme at full and partial load, 40°C cotton programme at partial load, Left-on mode and in off-mode. This choice comes from the analysis of user's habits. while in the past the high-temperature cotton cycle was the reference cycle, today people uses washing machines with a number of loads and prefers lower temperatures; furthermore, the actual washing machines include a lot of electronic devices – i.e. additional energy consumption - which operate also when no washing cycle is active.

Standards themselves are periodically reviewed, to take into account technological changes. For refrigerating appliances, the standard energy consumption is related to a "static" (e.g. without door opening or load operations) situation in a relatively severe boundary conditions (ambient temperature). It is considered a good approximation of the mean European kitchen, where ambient temperature is lower than the reference one, and simplifies the testing procedure.

Nevertheless, it is important to investigate user habits and define new testing standards, aimed to be more and more close to the real working conditions of appliances.

Moreover we observe that the standard conditions do not allow to exploit the energy saving potentials due to (new) technical solutions able to limit the air changes (by openings) within the cold compartments (e.g. some appliances switch on the controls immediately after each door opening, other appliances may use fuzzy logic or other devices to improve energy savings). This is the case of a new Indesit's prototype that ENEA will monitor in next few months, also defining *ad hoc* user schedules.

Characterizing the market of household appliances and the user profiles

General

To assess the effectiveness of the EU energy efficiency policy measures for household appliances on the national market an enquiry was developed by ENEA in the second half of 2010 to investigate the presence and the main energy efficiency and technical characteristics of the domestic appliances installed in the Italian households. The enquiry was developed in the framework of the Agreement between ENEA and the Italian Ministry for Sustainable Development [1].

The enquiry was realised through an on-line Questionnaire. It included questions with closed answers and was designed to last no more than about 20 minutes. The content of the questions was prepared by ENEA while the questionnaire layout and adaptation to the on-line environment and collection of the answers was done by the society ODC Services, a firm specialized in on-line interviews with a panel of 425.000 households in Europe. Among those having answered to the Questionnaire, and therefore owning a PC and able to use Internet, a sample of 3 000 answers was selected.

Within the participation in the Energy&Appliances 2015 project the Ispra Working Group of ENEA has promoted a monitoring campaign in the domestic and European context by involving the researchers of the European staff by the Commission DG JRC[2] of Ispra. JRC and ENEA have been collaborating in the promotion and implementation of their own researches especially in the energy sector within Memorandum of Understanding ENEA-JRC. The Institute for Energy and Transport - Renewable Energy Unit, the External Relations and the Green Team have supported this initiative.

Starting from a survey launched by ENEA in 2010, the questionnaire was revised focusing on the new target and the household appliances object to the project, while adapting the relative questions to the new European legislation on energy efficiency. The 2012 questionnaire was written both in Italian and English languages and made available online thanks to the collaboration with the ICT Technical Unit of ENEA in Casaccia (Rome) and Saluggia (VC). The survey was launched by the involvement of the Green Team within the JRC.

In order to find some similarities between this survey 2012 within JRC Ispra and the previous one (2010) promoted within Italian families, it is necessary to point out that the questions are not completely comparable as they refer to different communities and they have been adapted to different occupation profiles: the first one is targeted to a standard Italian family and the other is composed of personnel working in JRC-Ispra, coming from countries of the European Union. The JRC researchers have a medium-high professional profiles, often live in the surrounding area of Ispra, in municipalities with different population groups, overall only during the work week, some in residence and are aged 18-54 years.

The 25 participants in the survey were invited to apply to the monitoring campaign of the use of three kind of appliances during a week. Therefore during the month of January 2012 a logbook was filled in by 9 families. In accordance with the Company Indesit, only fridge-freezers, washing machines and dishwashers have been included in this monitoring campaign. The sheet was arranged to get back general information about the appliances and a weekly report of the use of it.

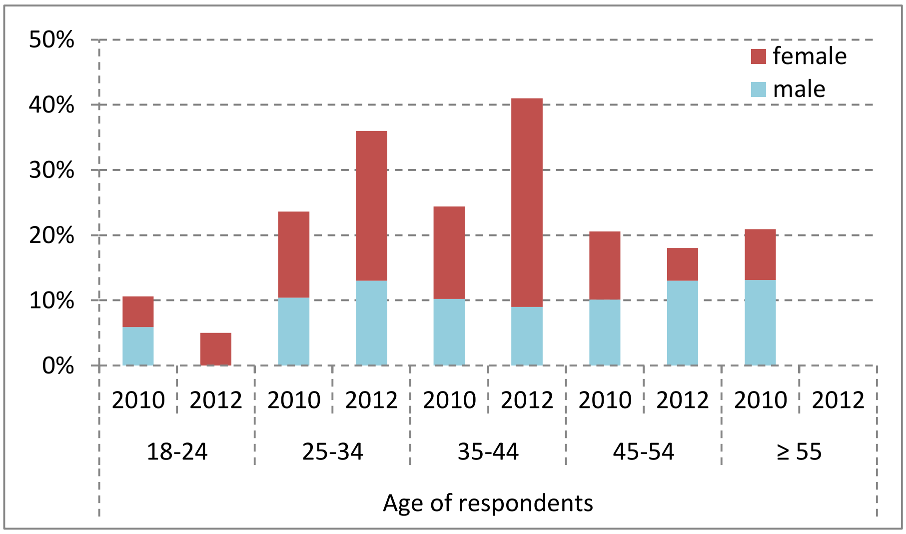

Figure 1 - Age and gender of the respondents to the 2010 and 2012 surveys.

Referring to Fig. 1 showing age and gender it is important to point out that the ODC investigation received the largest number of responses raised from the South and Islands with 35,4%, followed by North West regions with 25,5%, Central Italy with 20,3% and North-East regions with 18,8%. Participants in the 2012 survey lived near Ispra but came from different EU Countries.

[2] http://ec.europa.eu/dgs/jrc/index.cfme

Object of the survey 2012

The 2012 questionnaire was composed of two parts. The first section listed questions for private data of the compilers:

- Sex;
- Age;
- Nationality;
- Profession;
- Educational qualification;
- Composition of the family unit;
- Years of residence in Italy;
- Type of housing situation;
- Population of the town of residence;
- Types and quantity of household appliances own;
- Types and quantity of household appliances in wireless;
- Weekly use of the kitchen nook;
- % of energy consumption of the different appliances in the electric bill;
- Most energy consumers appliances;
- Relevance of the habits for energy savings;
- Behaviour of the family to save energy;
- Respect of the environment.

The second part, reported a new list of questions on the basis of the appliances used; in particular, for cold appliances (refrigerating and wine storage) we asked for:

- Volume (estimated and real);
- Age of the appliances (estimated or real);
- Type of installation;
- Type of cooling system;
- Use;
- Automatic defrost system and frequency of use;
- Refrigerator:
    - Presence and quantity of low temperature compartments (refrigerator);
    - Quantity of stars at the low temperature compartments (refrigerator);
- Freezer:
    - Type of loading door;
    - Type of cooling system;
    - Freezing of fresh food;
- Refrigerator-freezer:
    - Number of opening doors;
- Wine storage appliances:
    - Number of compartments at different temperatures;
    - Range of available variable temperatures;
    - Type of wine storage appliances.

Moreover additional questions (same for all types of appliances) were proposed about:

- Purchase through Governmental incentives;
- Noise level;
- Energy Efficiency Class;
- Knowledge of energy labelling;
- Use of Operating Manual;
- Usefulness of the Operating manual;
- Interpretability of commands;
- Criteria adopted for choosing a new appliance;
- Criteria adopted for the disposal of the old appliance;
- Comments on information provided by TV, internet, advertising materials.

During the monitoring campaign by logbook on the use of washing machine, dishwasher and cold appliances a list of information were asked. In particular, for refrigerator and freezer:

- Model and brank;
- Type of installation and location;
- Class of energy efficiency;
- Date of purchase (real or estimated);
- Dimension and volume;
- Equipment of devices (inner LED, humidity control, inner shelves, door pockets, fruit and vegetable drawers, tempered glass shelves, chill compartments);
- Cooling system;
- Controls (display and selector of program).

In the weekly diary the users were asked to report for each day their behaviours:

- Maintenance: cleaning of back of the appliance, of inner compartments and drawers for freezer and refrigerator respectively, cleaning of gasket.
- Daily actions: storage of cold food, freezer of fresh food, use of closed containers, storage of food according to different level of chill, number of opening.

General results

The following table lists 2010 and 2012 survey results, focusing only on appliances analysed in both surveys.

Table 1 – Sharp look at ownership and remarks to household appliances (2010-2012 surveys).

	Survey 2010	**Survey 2012**
Subject	Italian families	JRC community in Ispra
N. of questionnaire	3000 families out of 60,6 Mio of citizens	25 families out of 1600 researchers
Most owned appliances	Fridge-freezer or Fridge+freezer → 100% Washing machine → 95.3% Oven → 94.4% Cooker → 86.6% Dishwasher → 60%	Fridge-freezer or Fridge+freezer → 100% Oven → 84% Washing machine → 84% Dishwasher → 60%
Household appliances networking	Washing machine → 20.6% Oven → 18.2% Fridge-Freezer → 15.3% Dishwasher → 12.7% Cooker → 13.6%	Oven → 18% Fridge-Freezer → 17% Dishwasher → 13% Washing machine → 13% Cooker → 9%
Use of cooker	More time each days → 66.3% One time a day → 27.7%	One time a day → 59% More time each days → 36%
Incidence of appliances consumption on own energy bills	More than 75% → 7.3% Between 50% and 75% → 37.9% Between 20% and 50% → 46.2% Less than 20% → 8.7%	More than 75% → 14% Between 50% and 75% → 41% Between 20% and 50% → 27% Less than 20% → 18%
Most energy consumer appliances	Washing machine Electric Oven Dryer Dishwasher Fridge-freezer	Electric Oven Washing machine Dryer Fridge-freezer Dishwasher
Relevance of habits for saving energy	Yes → 60.1% Enough → 39.6% Other → 0.3%	Yes → 60% Enough → 32% Other → 8%
Behaviour of the family	Adoption of common rules → 72.5% Individual behaviour → 25.1%	Adoption of common rules → 72% Individual behaviour → 28%
Respect of environment	Enough → 60.5%	Enough → 59%

	Always → 32.6% Sometimes → 6% Low → 0.9%	Always → 41%
Knowledge of the energy labelling	Yes → 35.7% No → 34.5% I have heard → 29.8%	Yes → 97% No → 3%
Purchase incentivated by tax allowance[3]	Refrigerators – No → 33% Fridge-Freezer – No → 62.3% Freezer – No → 34%	Refrigerators – No → 63% Fridge-Freezer – No → 61% Freezer – No → 89%
Higher level of noise	Washing machine Fridge-Freezer Refrigerators Freezer	Freezer Wash-dryer Washing machine Dishwasher
Consultation of Operating Instructions	Often → 51.9% Always → 33.1% Sometimes → 13.3% Almost never → 1.7%	Always → 32% Often → 32% Sometimes → 20% Almost never → 16%
Remarks to Operating instructions	Useful → 55.1% Complex → 27.1% Incomplete → 21.6% Easy → 9.4% Exhaustive → 5.6% Useless → 1.8%	Useful → 52% Incomplete → 28% Exhaustive → 9% Complex → 8% Easy → 3% Useless → 0%
Criteria for purchasing a new appliance	Consumption Cost Brand	Consumption Brand Cost
Disposal of the replaced appliance	Retailer Garbage dump Leave it to other person	Retailer Garbage dump Leave it to other person
Judgment on information by media	Useful → 39% Tendentious → 34% Incomplete → 11.3% Often false → 8.4%	Incomplete → 42% Tendentious → 39% Useful → 11% Often false → 8%

In particular, we observed that:

- the vast majority of respondents judge themselves as people careful (very or fairly) to the energetic (92%-99%) and environmental (93%-100%) issues, implying that the nominal energy consumption of a new appliance is the most important criteria for purchasing;
- often (especially after purchase and until the useful programs are chosen) the respondents searching for information in the manuals, that they consider useful (52%-55%), but also incomplete (22%-28%) and complex (8%-27%);
- the information by media is often judged as tendentious or false (42%-47%) and incomplete (11%);
- the respondents of both samples did not recognize the cold appliances as the most energy consumer ones. Because, in general, the main household consumptions are due to these appliances [2] we impute these erroneous responses to an interesting misunderstanding

[3] In April 2010 the Italian Government issued a National decree promoting the replacement of dishwashers, electric ovens, hobs and other Household Appliances with energy labeling of the highest classes or more efficient ones. The incentives had been applied to buyers as a discount of 20% or reduction on price up to 2010. Even in the previous year a 20% tax deduction was issued for the purchase of low energy consumption appliances.

between energy and power, that don't allow a complete comprehension of the household energy consumptions.

Results about Cold appliances

2010-2012 surveys

The present paper will analyse in details only cold appliances. While considering the two surveys not comparable for the reasons mentioned before, an effort was made to find out their analogies.

Table 2 – Sharp look at characteristics of the installed refrigerating appliances (2010-2012 surveys).

Question		Refrigerator		Refrigerator-freezer		Freezer		Wine storage appliance	
		2010	2012	2010	2012	2010	2012	2010	2012
Energy efficiency class	A++	15%	20%	18%	8%	13%	11%	13%	0%
	A+	28%	20%	35%	33%	28%	11%	21%	100%
	A	24%	40%	21%	25%	22%	56%	21%	0%
	don't know	25%	20%	20%	33%	26%	22%	40%	0%
Installation	freestanding	51%	33%	62%	38%	82%	64%	n.a.	n.a.
	built-in	47%	67%	38%	62%	17%	36%		
	other	2%	0%	0%	0%	1%	0%		
Cooling system	static	30%	9%	20%	15%	36%	20%	n.a.	n.a.
	air-circulation	21%	9%	21%	15%	13%	0%		
	no-frost	27%	18%	38%	31%	20%	10%		
	don't know	22%	64%	21%	38%	31%	70%		
Low temperature compartments	4-stars	0%	0%	100%	n.a	100%	n.a.	n.a.	n.a.
	3-stars	41%	14%	0%		0%			
	2-stars	11%	14%	0%		0%			
	1-star	4%	15%	0%		0%			
	0-star	8%	0%	0%		0%			
	don't know	37%	57%	0%		0%			
Number of doors and configuration	combi	n.a	n.a	49%	42%	n.a	n.a.	n.a.	n.a.
	2 doors			45%	58%				
	side-by-side			4%	0%				
	>2 doors			1%	0%				
Purchases with state incentives?	No	89%	62%	88%	48%	91%	45%	n.a.	n.a.
	Yes	11%	38%	12%	52%	10%	55%		
Noise	No	78%	75%	80%	62%	70%	91%	n.a.	n.a.
	Yes	18%	25%	16%	23%	12%	9%		
	don't know	2%	0%	3%	0%	1%	0%		
	installed in another room	2%	0%	2%	15%	18%	0%		
Average age	Years	6.8	5.5	6.0	5.3	6.5	4.5	5.3	

Average volume	Litres	128.2	n.a.	159.2	201.7	129.1	89.4	n.a.	n.a.

In particular, we consider interesting to note that:

- on average, the most common energy class of cold appliances in use at home is A+, and class B and C are no longer represented unlike samples of period 2007-2008 [3]; the lower presence of appliances at the highest level of energy classes in 2012 is justified by the different sample analysed;
- many users do not know the energy class and the type of cooling system of their own cold appliances, as well the quantity of stars of the refrigerator units;
- the purchases with state incentives of the JRC Community (in 2012) result significantly higher (+30-35%) than the Italian ones in 2010;
- that the average age of cold appliances was reduced (from 6-7 years to 4.5-5.5 year) moving from national to local community (over the period 2010-2012).

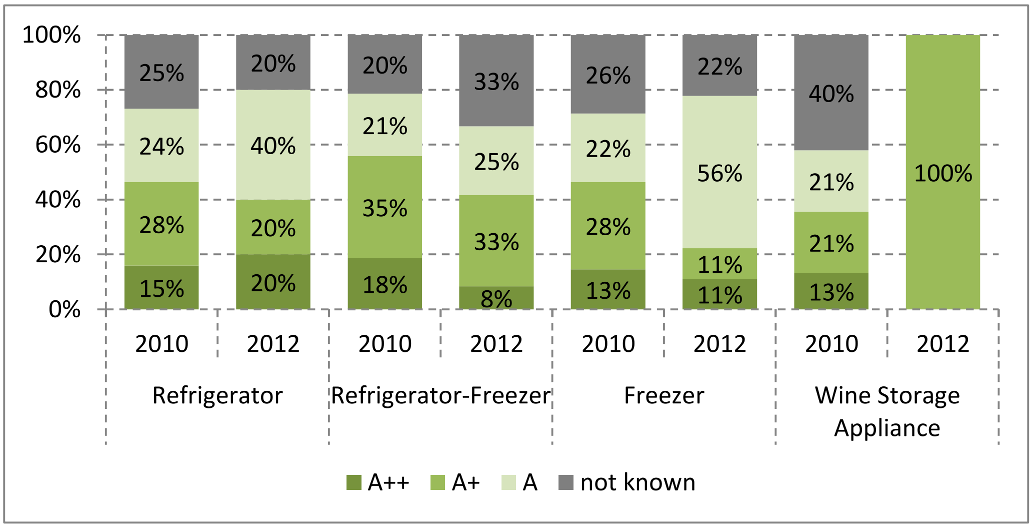

Figure 2 – Sharp look at energy class of cold appliances (2010-2012 surveys).

As shown in Table 3 the survey 2012 aimed also at analysing the personal habits in the use of the appliances.

Table 3 – Personal habits in the use of the cold appliances (Questionnaire 2012).

Question		2012
freezer of fresh food	always	6%
	often	50%
	sometimes	31%
	never	13%
use of freezer for fresh food	lower of the temperature of thermostat	0%
	use of fast freezer / super cool switch	27%
	neither of them	73%
automatic defrost	yes	43%
	no	57%

defrost frequency	once a month	0%
	once every 3 months	15%
	once every 6 months	23%
	once a year	54%
	never	8%

Monitoring activities by logbook 2012

All 9 participants have reported the brand of their appliances; only more than half of them reported the model.

All but one model was built-in, the other were self -standing, with freezer on the bottom. Most of them are in class A+ (45%), one in class A++. Bought in 2005 - 2011 with an average age of 4 years, all refrigerating appliances are in the kitchens.

All appliances are 2-5 shelves, 67% in tempered glass, have door pockets (75%), fruit and vegetable drawers (89%) and a fresh food compartment (50%). 56% of them do not have inner LED. The humidity control is installed in 38% of the refrigerators. Often the users do not know some features, over all inner LED (56%) and the humidity control device (25%).

Table 4 – Features and functions of the refrigeration appliances monitored by logbook.

	Inner LED	**Humidity control**	**Door pockets**	**Fruit and vegetable drawers**	**Tempered glass shelves**	**Fresh compartments**
Yes	22%	38%	75%	89%	67%	50%
No	56%	38%	13%	11%	22%	38%
Not known	22%	25%	13%	0%	11%	13%

Programs are selected by manual switch by 75% of users, the remaining 25% by touch control. 71% of the appliances do not have a display, while 29% has a LED display.

Elaborating the data of the logbook we obtained the results shown in Figure 3.

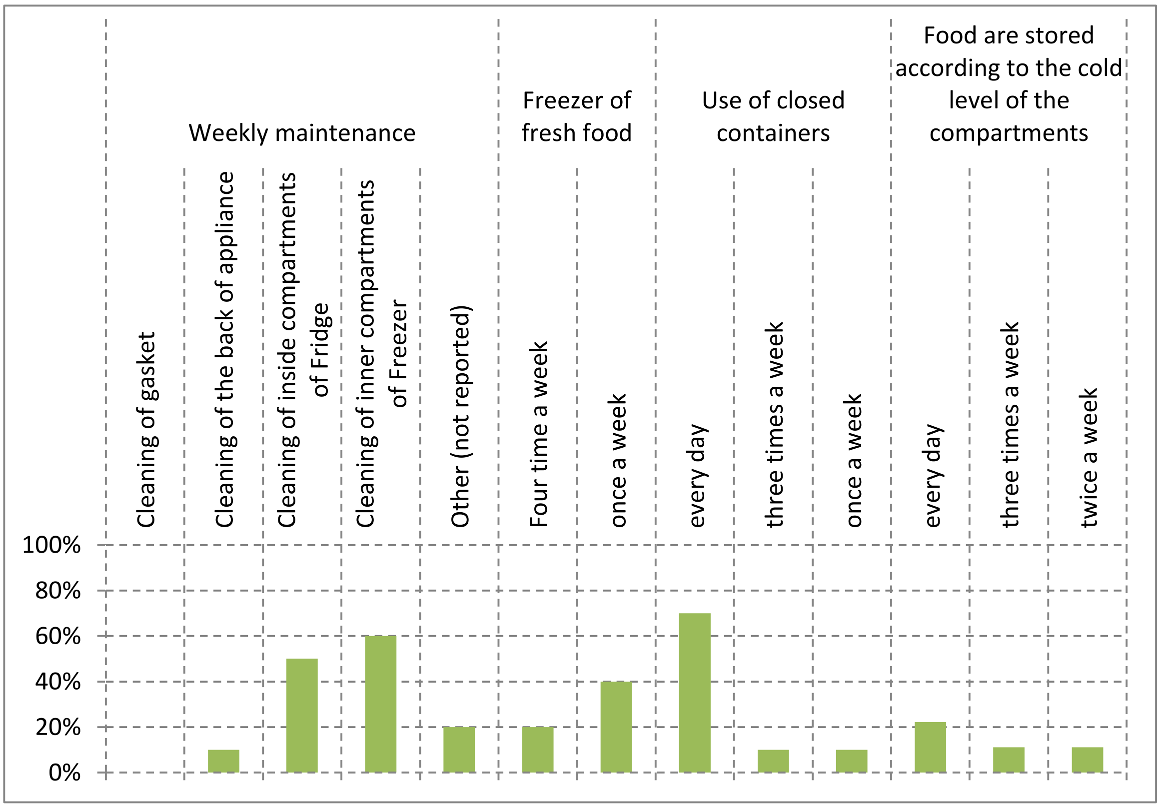

Figure 3 – Personal habits in the use of the cold appliances (Logbook 2012).

The form sheet of the weekly recordings shows that 40% of users do not freeze fresh food and the same percentage don't freeze ever. All users use airtight containers to store food, 78% of them on a daily base. Half of the users does not place the food into the specific cold level of the compartments, 22% performs this operation daily while 11% respectively 2 or 3 times a week. 10% of the users store hot food in the refrigerator for up to 4 times a week.

Cold appliances have been opened 512 times, with a weekly average per unit of 57 times and 8 times daily. Under item "other" a user reported the number of openings in the freezer, with an average of one day opening.

Defining common user profiles for energy assessment

Starting from the data collected we defined new test procedures, able to consider standard user profiles unlike the standard methodologies (EN ISO 15502:2005 [4] and EN 153:2006 [5]) used to certify the cold appliances.

In general, the main factors that affect the energy consumption of a cold household appliance are:

- external air temperature (environment);
- air temperature within the unit (setting of thermostat);
- opening of doors (frequency and duration);
- inserting of loads (food or drink) and their temperature;
- proximity to other heat sources;
- ventilation conditions;
- condition of the seals.

Aware of this, we decided to set up a weekly user schedule for a family of 3 people, defined as follow:

- intermediate setting of the thermostats with respect to the two standard tests of energy consumption;

- opening of refrigerator and freezer doors during the day (Figure 4);insertion of thermal loads in the refrigerator, simulated by test packs and trays of water (Figure 5);
- insertion of thermal loads in the freezer, halved compared to standard tests (Figure 5);
- rotation of the loads in the fresh food compartment and freezer;
- freezing (with function super-freezing) of a mass equal to the freezing capacity declared (5 kg) once a week (on Wednesdays).

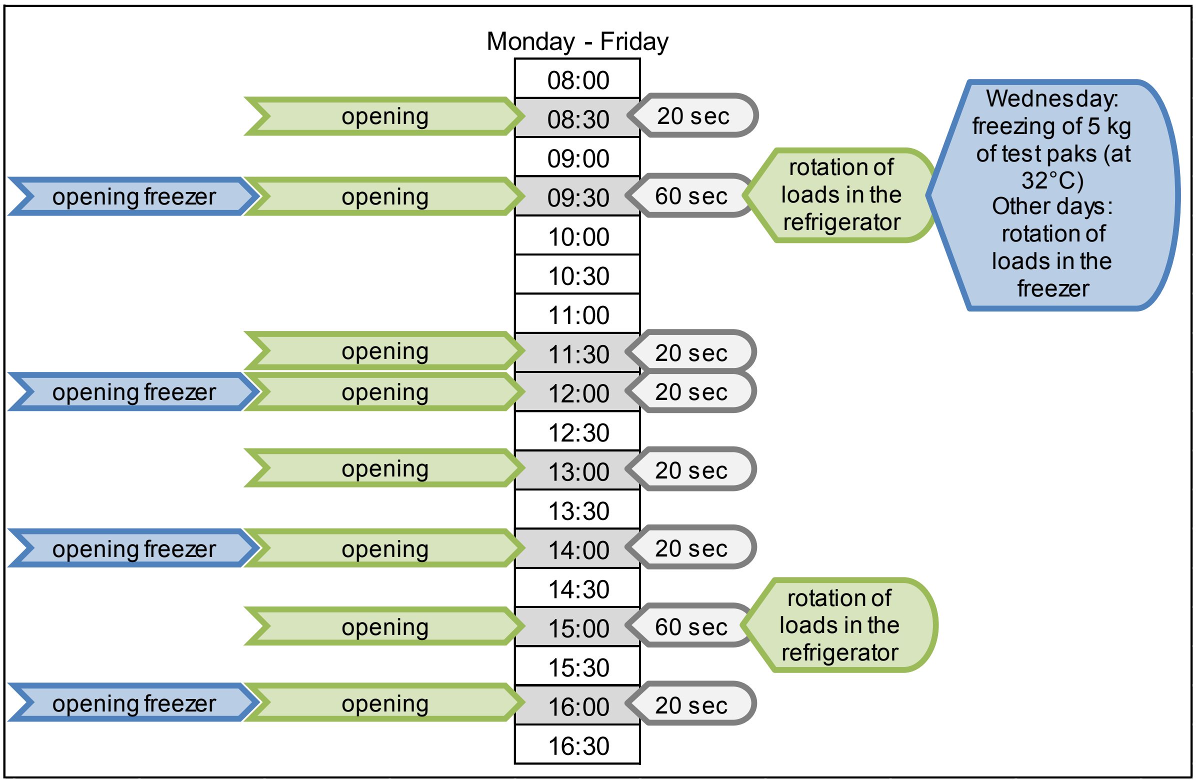

Figure 4 – Weekly user schedule.

(a) (b) (c)

Figure 5 – Thermal loads used within the refrigerator (a, b) and the freezer unit (c).

Setting different environmental air temperatures (19°C, 25°C and 32°C), several tests have been carried out on a testing appliance, obtaining the energy consumptions shown in the following table.

Table 5 – Results obtained applying the new test procedure.

[kWh/day]	**Test 1**	**Test 2**	**Test 3**
	T_{env} = 25°C	**T_{env} = 19°C**	**T_{env} = 32°C**
Monday	1.45	1.12	2.08
Tuesday	1.45	1.16	2.10
Wednesday	1.71	1.50	2.24
Thursday	1.57	1.17	2.30
Friday	1.41	0.91	2.14
Saturday	1.17	0.89	1.84
Sunday	1.28	1.00	1.82
Daily average consumption	1.43	1.11	2.07
% difference respect the declared consumption	34%	4%	93%

Conclusion

Within the Energy&Appliances 2015 project, ENEA characterized the Italian market of household appliances and defined characteristic user profiles, also to evaluate the deviation between the real and the standard conditions now applied for energy certification.

Starting from the results of surveys here presented, some general recommendations can be provided:

- The contents of the manuals must be implemented, perhaps with an additional booklet for quick reference. However, it should contain all technical specifications of the appliance and practical tips to reduce energy consumption. Often the user has indicated a lack of knowledge of the requested information or adopted a more efficient use of the device.

- It would be more appropriate to carry out checks on the information transmitted by the media, having been judged often false and misleading, as required by the Framework Directive 2010/30/EC, as well as to perform more targeted and widespread information campaigns at sale's points by trade associations and independent third parties.

About the monitoring analysis carried out, we observe that the simplifying assumptions of standard measurement procedure have a small impact (-4%) only if a low ambient temperature (19°C) is considered applicable (e.g. freestanding appliances, away from other heat sources): the imposition of a high standard T_{env} (25°C) balances failure to consider door openings, thermal load insertions, freezing operations, etc.

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Consumer-relevant assessment of automatic dishwashing machines by a new testing procedure for ‘automatic’ programmes

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Abstract

A new procedure for ‘automatic’ dishwasher programmes is developed and tested under laboratory conditions in comparison to the standard test programme (called Eco programme) to increase the comparative aspect of dishwasher testing and the consumer relevance of current dishwasher test standard EN 50242/EN 60436. It is assessed if the sensors in the ‘automatic’ programme are able to detect the current usage conditions and react adequately with varying amounts of load and soil. Due to the fact that consumers tend to underestimate the loading capacity of their dishwasher and that the amount of soil found in dishwashers at home is lower than in the standard, the new approach focuses on lower amounts of dishware and soil to be cleaned in a dishwasher using the “automatic” programme. Five different scenarios with one to three repetitions are tested and, while the highest level is a test with 100% of the rated loading capacity and soil, the amount is lowered until the machine is tested completely empty.

The comparison between the Eco and the ‘automatic’ programmes reveals big differences in the average consumption values, and also concerning the capability of the machine to adapt the programme course depending on the conditions applied. The results of the tests emphasise the importance of extending the test portfolio of household dishwashers and including the results of the ‘automatic’ programme test scenario onto the energy label. This would enhance the up to now limited information on dishwasher performance and consumption values due to testing only one programme with maximum load and soil. It is of great importance that the combination of low consumption and high performance values, which is essential for most consumers, is not only considered in the Eco programme, but also in the second most used ‘automatic’ programme under different consumer-relevant load and soil levels.

Introduction

Environmental aspects concerning the use of household dishwashers

Food preparation and eating generate dirty dishes in every household, and these need to be cleaned either manually or in a dishwasher. Even though the market penetration of dishwashers differs from country to country with penetration levels up to 70%, the number of households owning a dishwasher is still increasing in all European countries. More than six million dishwashers are sold per year in EU [1]. Therefore, it is not surprising that the domestic dishwasher is one of the most intensively studied energy-consuming products, with the aim of reducing its electrical energy consumption [2]. The share of residential energy consumption which could be allocated to dishwashers in 2007 was 2,7%, which seems less in comparison to heating systems (18,7%) or cooling appliances (15,2%) but, nevertheless, leads to an annual energy consumption for household dishwashers of 21,5 TWh [1]. This high value emerges even though it was possible to reduce the average energy consumption of a dishwasher from 2,56 kWh per cycle in 1968 to 1,035 kWh per cycle in 2005, which means an improvement in energy efficiency of more than 50% [3]. A major reason for the significantly reduced energy consumption, along with enhanced technologies, is the reduction of water needed to clean the stated number place setting (ps) load in a modern dishwasher. Dishwashers are currently offered on the market which need 6,5 L of water and 0,93 kWh of energy to clean 13 place settings [4]. If new technologies, such as an automatic door-opening function or zeolite granules which rapidly adsorb moisture from dishes, are used, the dishwasher’s electricity demand can be further reduced to values between 0,82 and 0,86 kWh [5]. If consumers are asked about the four most important aspects or features when purchasing a new white goods appliance, the research of Richter found that 83 % of the participating households are focused on buying a household appliance with low water and energy consumption [6].

Since the early 90ths the European Commission, as the driving force for the implementation of the Eco-Design and the Labelling Directive, is advancing those reductions through mandatory labeling. The labelling, first implemented by the Council Directive 92/75/EEC in 1992 requires informing the consumer about resource consumption and performance values of household appliances. The improvements induced through this and following measures can be seen in the fact that about 90% of the dishwashers in 2005 belonged to energy efficiency class A, and no devices were worse than class C, whereas only about 9% in 1999 were located in class A, and a third were worse than class C [2].

Since 2010 the commission regulation No. 1059/2010 describes the layout for the new dishwasher label and the values which have to be declared on the label and in the product data sheet. The label now depicts the energy efficiency of a dishwasher model using a system ranging from A+++ to D. It provides data on energy efficiency, annual energy and water consumption, drying performance, capacity, and airborne acoustic noise emission. Due to the fact, that the commission regulation No. 1016/2010 requires a minimum cleaning efficiency, the cleaning performance is no longer declared on the label. The values displayed on the label are measured in the standard programme for a normally soiled load, which is called 'Eco' programme [7]. The Eco programme is supposed to be the most energy efficient programme to clean normally soiled dishes. However, the definition of the term 'normally soiled dishes' has to be discussed, especially when consumer habits and usage conditions are taken into consideration. Only slightly soiled items could be cleaned at even lower consumption values if the machine reacts to them accordingly. Such an adaptation to the real usage conditions is often advertised for 'automatic' programmes, which are, to date, the second most frequently used programme, if available [8].

European dishwasher test standard EN 50242/EN 60436

The basis for the European Energy Label declaration of household dishwashers is the European Norm 'EN 50242/EN 60436: Electric dishwashers for household use: methods for measuring the performance' of 2008, which gives detailed instruction concerning cleaning and drying performance tests and the measurements of consumption values [9]. The EN 50242/EN 60436 is very similar to the international dishwasher test standard IEC 60436, but includes some necessary adjustments (e.g. more precise descriptions about soils to use or the drying of the load) for the EU labelling. Following this standard a well-defined amount of dishware is soiled with a well-defined quantity of soiling under standardised ambient conditions with specified water and room temperatures, humidity, water

pressure, and electricity supply (Figure 1).

Figure 1: A 12 place setting load soiled according to the EN 50242/EN60436 [Source: own picture]

The capacity of a dishwasher is defined by the number of place settings it can hold. A place setting is a set of crockery, glassware and cutlery representing the amount of dishware used by one person. The majority of dishwashers are able to load at least 12 ps, i.e. 140 items. One of seven different types of soiling is applied to each item (except for the knives, teaspoons and dessertspoons), which amounts to a total soiling amount of 130 g. Either egg yolk, spinach, minced meat, milk, tea, oatflakes, or margarine is precisely specified and applied. The soiling is dried in a thermal cabinet for two hours at 80 °C after application. Afterwards, the dishes are placed into the test machines in accordance with the loading plan prescribed by the manufacturer. The test cycles are run in the Eco programme using detergent, while the consumption data is monitored. After the programme has ended, the cleaning performance of each item is visually evaluated with a cleaning performance scale ranging from 5 (free of stains) to 0 (full of stains). Either the soiled area or the number of discrete soil particles is assessed on each item. Subsequent to the cleaning performance evaluation, the drying performance is assessed in a separate cycle. Here the same programme is run with a clean load, detergent and rinse aid without measuring the consumption values. To assess the drying performance, the amount of water remaining on the dishes is evaluated visually with a scale from 2 (dry) to 0 (2 wet spots or more).

Consumer behaviour versus European declaration and assessment conditions

Several studies have been conducted which directly or indirectly show that the conditions to test and classify a dishwasher are often different from the usage conditions in the households. A German study of 1999 revealed that the way of soiling the place settings described in the dishwasher test standard does not correspond to consumer reality because the amount of soiling is too high and some components (e.g. proteins) are over-emphasised [10].

According to Richter, the average number of dishes in European household dishwashers is more than 50% lower than in the dishwashing standard [11] and also the relative distribution of materials cleaned in a dishwasher is different. Regarding the dishware used, the consumer study from Zott showed that the loading behaviour and the style and shapes of the items used differ between the household and the test standard EN 50242 [12]. The authors were surprised by the variety of materials and the high number of plastic items found in consumers' dishwasher loads.

Sensors in household dishwashers

'Automatic' programmes in a dishwasher should adapt the programme structure to the conditions given. Those conditions may be determined through parameters such as the actual soil level, the materials used or the amount of load, and can be closely monitored by different sensors. The sensor signals serve as input data for control systems which transfer, process and analyse the signals and, due to circulation loops and fuzzy logic, adjust the control variables to achieve a good cleaning and drying result at lowest consumption values automatically [13]. The potential to utilise sensors in 'automatic' dishwashers is manifold and over the last years more and more sensors and microsystem devices are being used in household appliances [14]. Measuring the turbidity, or more precisely the optical transmittance and reflectance of the wash-water allows estimations about the water quality and the amount of soil dissolved in the fluid. While light-emitting diodes (LEDs) are used to emit the light, the radiation is often measured with photodiodes. In the course of turbidity measurements, parameters such as different wavelengths of emitted light, light polarisation, varying incidence angles of radiation, location of the sensors, different numbers of emitting or receiving sensors, and the frequency of measurements play an important role during the attempt to differentiate precisely between altering amounts and kinds of soil (e.g. small or large particles). The turbidity values measured at certain points in time are compared to data of known kinds and amounts of soils to optimise the programme cycle concerning water-changes, detergent dosage, programme duration, or selectable temperatures [15]. A further factor according to which the programme structure of a dishwasher could be adapted is the amount of load. The energy consumption of a dishwasher is influenced by the different heat intake capacities which depend on the amount of dishware and the material employed. Many different approaches are made to determine the amount and composition of dishware placed in the dishwasher. One possible method is the determination of the load-related change in thermal capacity of the actual dishwashing cycle. According to this concept, the heating up or cooling down rates of the wash-water are measured via temperature sensors and analysed. Large loads change their temperature more slowly than small loads and, therefore, the temperature trend recorded of the wash fluid can be used as a measure for the load [16].

Objective

For testing dishwashers, the environmental, the consumer-related and the comparative aspects have to be taken into consideration. But ‘automatic’ dish cleaning is a complex task, and the interactions have to be taken into consideration to combine high performance results with low consumption values. Several in-house studies have shown that many different amounts of load and soil and varying dishware shapes and materials occur in real life. By choosing ‘automatic’ programmes, the consumer may be disburdened from the task to choose the adequate programme for different types and amounts of dishes and different soiling levels but he still expects to get clean loads. Nevertheless, low consumption values are also requested by the consumer. To test this and to increase the differentiation between machines, a broader test portfolio for energy labeling may be useful, including tests of ‘automatic’ programmes. ‘Automatic’ programmes, which are most frequently used after the Eco programme, are today not included in labelling tests but manufacturers promise good results for all kinds and amounts of dishware at low energy and water consumption. If a scientifically sound test procedure for ‘automatic’ programmes with varying and consumer-relevant test conditions can be developed a more realistic real life energy and water consumption can be assessed.

Therefore this study aims to:

- Develop and verify a procedure to test the adaptation of ‘automatic’ programmes of dishwashers to varying amounts of soil and load to be cleaned.
- Compare the Eco and ‘automatic’ programmes of different dishwashers concerning their capability to deliver a good cleaning performance under fixed or varying conditions together with low consumption values.
- Present recommendations to increase the expressiveness of the current Energy Label and demonstrate means how the test portfolio for household dishwashers could be extended by including tests of ‘automatic’ programmes.

Material and Methods

Laboratory conditions and measurement of consumption values

All tests are performed in the laboratory of the Household and Appliance Technology Section of the University of Bonn. The values for the ambient conditions and the water and electricity supply fulfill the requirements specified in the EN 50242/EN 60436 [9] and are recorded and assessed to guarantee that they lie within the given tolerances to obtain reliable results of the relevant performance and consumption values.

Machines and programmes tested

Four household dishwashers are used for the tests: machine 1 to machine 4. They are either labelled according to the ‘old’ labelling regulation 97/17/EC or according to the ‘new’ regulation 1059/2010. Each machine is tested in the Eco programme used for declaration purposes and the ‘automatic’ programme available.

Detergent and rinse aid

The new reference detergent type D of the draft of the 4th ed. IEC 60436 [17] is used. The actual amount of detergent used for each test is calculated depending on the number of place settings used for a 100% loaded, a 50% loaded and an empty machine by adding 1 g per place setting to a fixed amount of 8 g per test. The reference rinse aid formula III ‘acid’ is used [17] in the settings recommended by the manufacturers of the four machines. The water softener for all machines is adjusted manually or automatically according to the manufactures' instructions depending on the water hardness of 2,5 mmol/l used for the tests.

Dishwasher test load and soils applied

The employed new load has been developed during the revision of the 3rd ed. IEC 60436 and is one of the major improvements established in the draft of the 4th ed. IEC 60436 [17]. The porcelain share of the current standard test load is reduced significantly to align the new load to the data assessed in the different in-house studies, and two pots and eleven plastic items are introduced. Additionally, more different glass and porcelain items are used to increase the variety of different shapes. Furthermore six porcelain cups are replaced by six porcelain coffee mugs, and six small glass bowls and one large glass bowl are added. While the kind of soils, their specifications, the requirements concerning their preparation, and total amounts are similar to the current EN 50242/EN 60436 [9], the way of application and the amount per item is often changed and is described in the draft of the 4th ed. IEC 60436 [17]. All items except the clean cutlery and the melamine serving pieces and bowls are placed in the thermal cabinet at 80 °C to fix the soil on the surfaces.

Combined cleaning and drying evaluation

The cleaning and drying performance assessment is carried out in a combined cleaning and drying evaluation as described in the draft of the 4th ed. IEC 60436 [17].

Test procedure for 'automatic' programmes

The total amount of soil and the number of load items is varied in five different tests scenarios to test the adjustment of the machine to varying load and soil conditions. The tests are carried out with the same dishware, the same kinds and amounts of soil applied on the specific items, and the same evaluation procedure. The amount of test load, the total amount of soil, the necessity of a cleaning and drying evaluation, and the number of cycles tested per scenario is described in Table 1.

Table 1: Test scenarios for testing 'automatic' programmes

Scenario	Amount of test load	Total amount of soil	Evaluation of the cleaning and drying performance	No. of cycles	Labelled as
a	100%	100% soil	with evaluation	3	Auto_100%load/soil
b	100%	no soil	without evaluation	2	Auto_100%load/no soil
c	50%	50% soil	with evaluation	2	Auto_50%load/soil
d	50%	no soil	without evaluation	2	Auto_50%load/no soil
e	no load	-	without evaluation	1	Auto_no load

A full load is used for three cycles, i.e. the dishwasher is loaded with the number of place settings declared by the manufacturer as rated capacity. To determine the amount of test load for the half load, the number of place settings for a full load is halved and rounded up to an integer number. A reduction of soil to 50% accompanies the load reduction of 50%. With a 50% load, the dishwasher is loaded similarly to the loading scheme for a 100% load, but every second position is left free. As it is not necessary to evaluate an originally clean load, the cleaning and drying performance evaluation is not an obligatory part of each test scenario.

Results

Programme characteristics of the different machines

Important parameters to define a dishwashing cycle are the number of water intakes, the temperatures in the cleaning and drying phase and the duration of the different programme steps. All these parameters are subjected to the design criteria specified by the manufacturer and vary more or less for different programmes or machines (here exemplary discussed for machine 3 and 4). The total water intake in the Eco programme is divided into three to four smaller water intakes characterised by the declining temperatures when fresh water of 15 +/- 2 °C flows into the sump of the machine (Figure 2). The programme starts in both machines with a pre-cleaning of the dishes with cold water of about 20 °C for 10 to 20 minutes. After this pre-cleaning phase, the water is heated to temperatures between 44,7 °C and 47,7 °C. The heating up rate mainly depends on the amount of water used during the cleaning phase, the heat capacity of the load and the power of the elements. The subsequent drying phase is defined by a temperature between 62,9 °C and 64,3 °C in both machines.

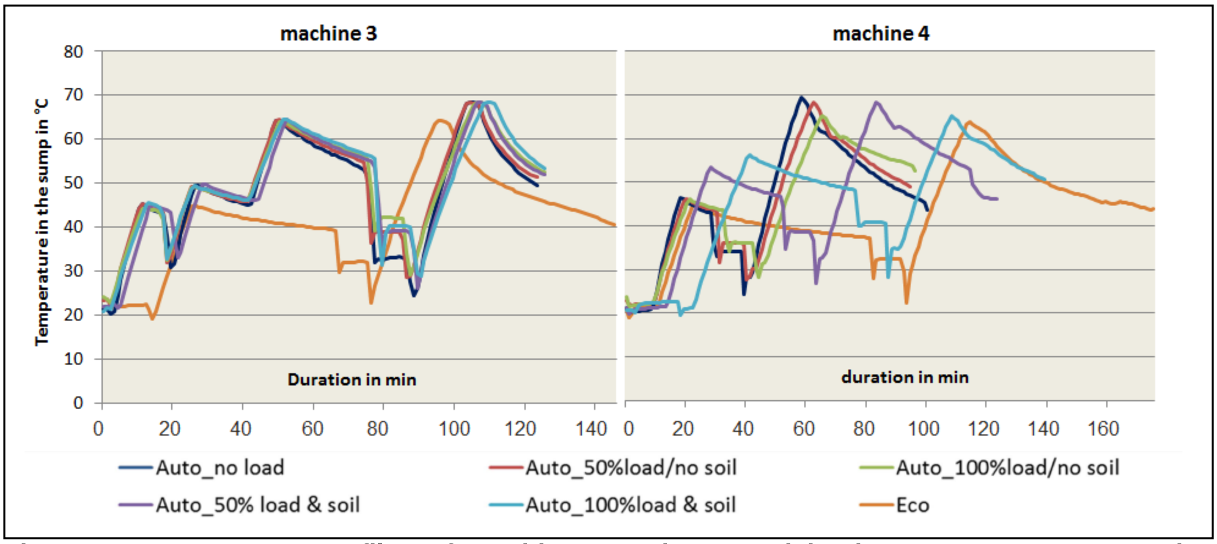

Figure 2: Temperature profiles of machine 3 and 4 tested in the Eco programme or the different scenarios of the 'automatic' programme (Source: own data)

Machine 3 reveals the fewest differences in the 'automatic' programme because the programme courses for all scenarios look approximately alike and the temperature profiles mainly overlap each other. The programme profiles of the five scenarios are characterised through four water intakes of about 4 L each, a maximum cleaning temperature of approximately 64 °C and a maximum drying temperature of about 68 °C. After the pre-cleaning phase of 16 min, a cleaning phase follows where the temperature is increased in two steps. The intermediate rinse and the drying phase follow. The only noticeable differences in this graphical rendition are the different temperature increases in the intermediate rinse and the slightly varying rates of the temperature increase. When the machine is fully loaded with 12 place settings, the stored heat capacity in the dishes leads to a higher warming up of the inflowing cold water during the intermediate rinse than when only half-loaded or empty. Additionally, it takes slightly longer to heat up the complete load than reduced amounts.

In contrast to this machine 4 reveals a broad range of possible programme courses, and reacts slightly differently in each scenario tested. Despite the general increase of the temperature from clean load to soiled load, an adaptation can even be seen from 50% of load&soil to 100% of load&soil. When fully loaded with completely soiled dishes, four water intakes were measured, while the number is reduced to three for all other scenarios. The different amounts of load are clearly mirrored in the different heating up rates of the scenarios. A load-related delay can be seen in the temperature increase in the cleaning and drying phases, especially when different amounts of clean loads are used. The delay does not influence the maximum temperature during the cleaning phase, while the maximum temperature in the drying phase decreases with increased amounts of load. The empty machine is heated up to 69,3 °C within 15 minutes, while 20 minutes of heating in the drying phase are measured for 50% and 100% of load. The same input power and heating duration leads to a temperature of 65,2 °C when 100% loaded, and 68,3 °C when only partially loaded.

Energy consumption values

The energy consumption values for machines 2 and 3 in the Eco programmes are always clearly lower than in the different test scenarios of the 'automatic' programme, while the assessment of the values of machines 1 and 4 shows diverging results (Figure 3).

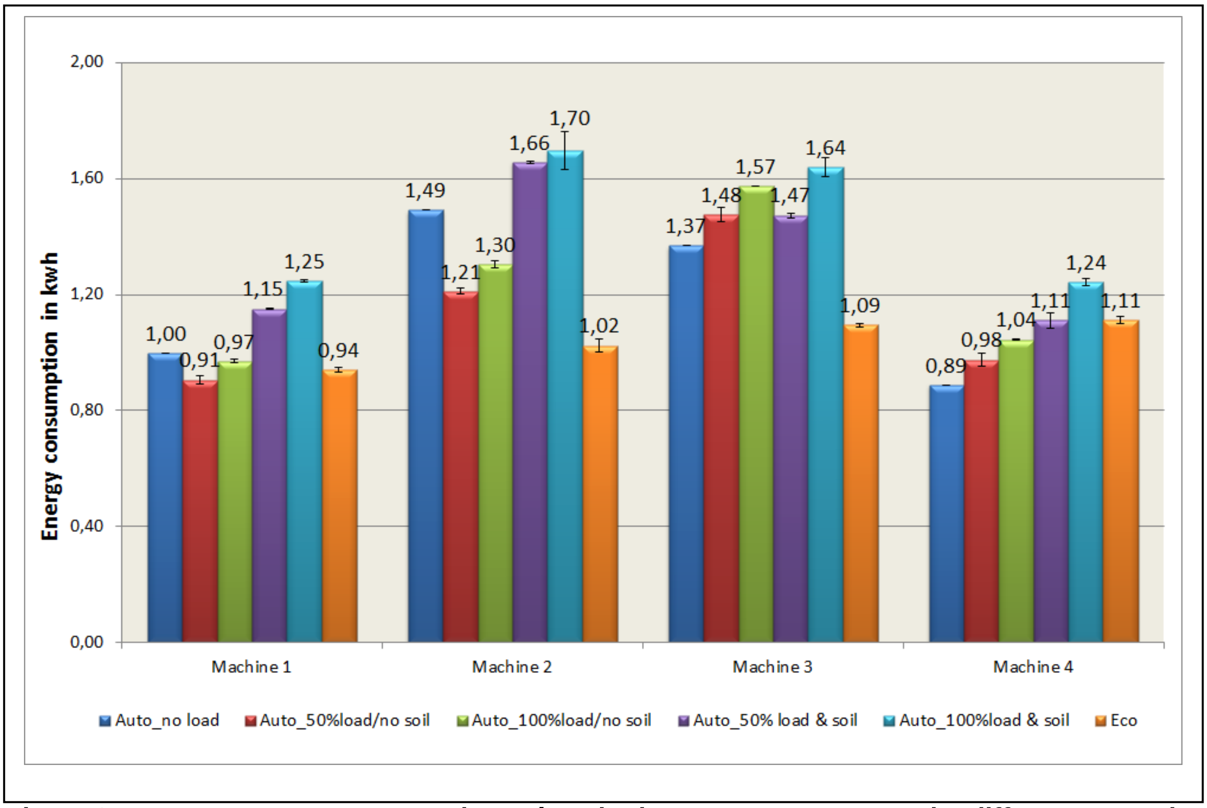

Figure 3: Average energy consumption values in the Eco programme or the different scenarios of the 'automatic' programme

Machine 4 reveals the highest average energy consumption in the Eco programme during the laboratory tests, but it is also the only machine where four of the five 'automatic' programme test scenarios tested have equal or lower values than in the Eco programme. In addition to that, machine 4 presents a gradual increase for each scenario from 'Auto_no load' to 'Auto_100%load&soil', while machines 1 and 2 are characterised through rather steep increases from scenarios without soil to those with soil. Machine 1 has the lowest energy consumption in the Eco programme, but this low value can only be reached during the tests of the 'automatic' programme in one scenario. Machines 1 and 2 have an exceptional programme course when tested without any load and this leads to energy consumption values which are higher in the 'Auto_no load' scenario than when tested in the scenarios with clean load.

Comparison of the Eco and the 'automatic' programme

The percentage differences ((Auto-Eco)/Eco)*100 between the average consumption and performance values of the Eco and the 'automatic' programme are displayed in Figure 4. The average energy consumption increases from the Eco to the 'automatic' programme for machines 1, 2 and 3 and this increase varies between 15% for machine 1 and 46% for machine 2. Although machines 1 and 4 have the same absolute energy consumption values in the automatic programme, the difference to the Eco programme is -2% for machine 4 and +15% for machine 1 because the consumption values in the Eco programme were different.

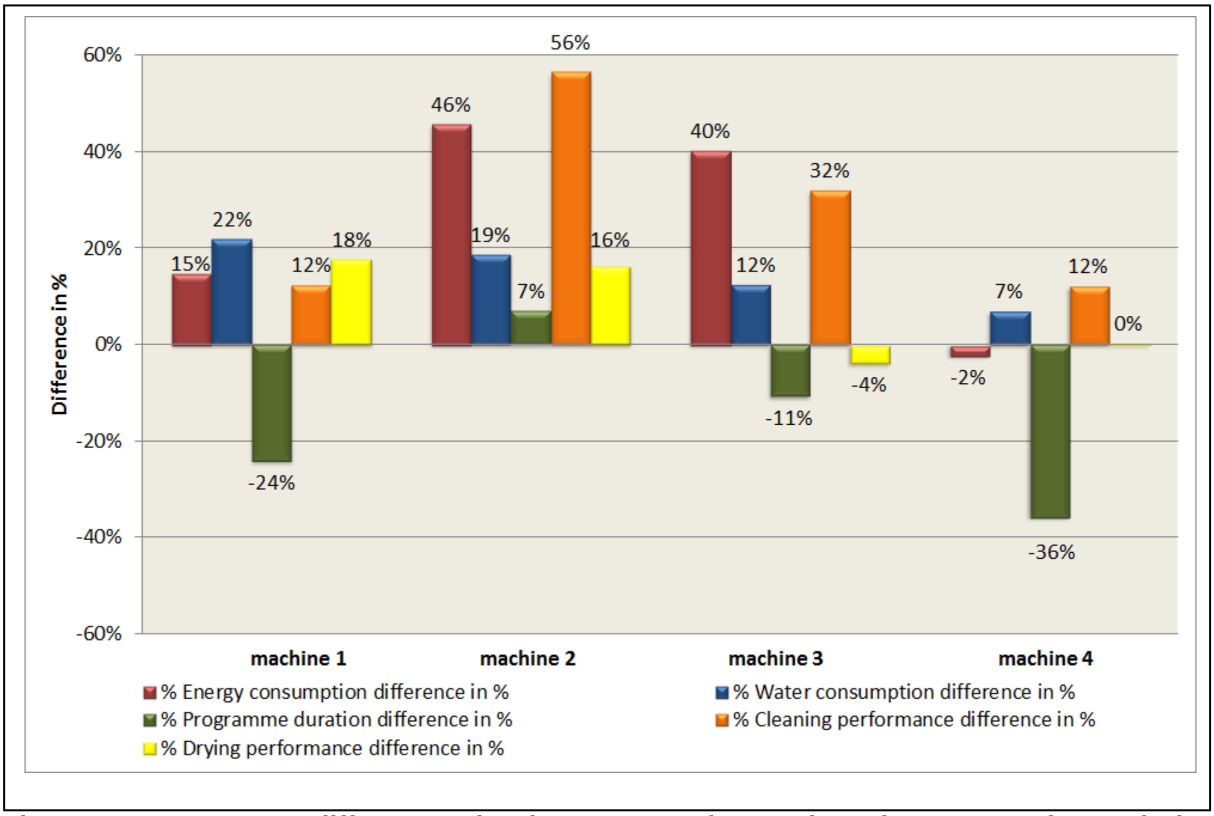

Figure 4: Percentage differences in the consumption and performance values of the ‘automatic’ programme in comparison to the Eco programme

All machines reduce the programme duration between 11% (machine 3) and 36% (machine 4), except for machine 2, which requires 7% more time in the ‘automatic’ programme than in the Eco programme. The differences in the cleaning and drying performance values are associated with different resource or time inputs. Quite large increases of the average cleaning performance in the automatic programme can be observed for machines 2 (56%) and 3 (32%), while machines 1 and 4 reveal 12% higher results. Minor changes are noticeable for the drying performance, for machines 3 and 4, while increases up to 18% are visible for machines 1 and 2.

Discussion

The previous assessment shows that the Eco and the ‘automatic’ programmes reveal large differences between those programmes and between the machines. This may be used to increase the differentiation between dishwashers. One possible way to compare appliances and to increase the consumer’s awareness of the energy and water consumption is the current European Energy Label. It depicts efficiency ratings, the annual energy consumption (AE_C) and the annual water consumption (AW_C), based on values measured in the Eco programme. Due to the fact that the Eco programme is not the only programme used, a more real-life-based differentiation between the dishwashers placed on the market through introducing automatic programmes may facilitate the purchase decision. Low energy and water consumption values are, at 83%, very important parameters for the consumer during the purchasing phase [7]. Focusing solely on the first parameter, the energy consumption, it is interesting to see that the difference between the four machines tested is quite small when the values measured in the Eco programme are taken as a basis. However, clear differences can be seen when the average values over all scenarios of the ‘automatic’ programme are used for the calculation of the AE_C (Table 2) according to the labelling regulation 1059/2010/EU [18] (similar to the preparatory studies for the Eco-design requirements of EuPs, the standby power consumption for this calculation is assumed to be 2 W for all machines during the left-on mode and 1 W during the off-mode [19]). If the AE_C is only based on the values of the Eco programme (AE_C 100% Eco), the difference between the machines is 49 kWh at the most while based on the usage of the ‘automatic’ programme it is 127 kWh.

Table 2: Differences in the annual energy consumption of the machines tested based on the average values of the Eco or 'automatic' programme

	AE_C 100% Eco	AE_C 100% Auto	Difference AE_C 100% Auto to AE_C 100 % Eco	
			Absolute	**Percental**
machine 1	288 kWh	328 kWh	+ 40 kWh	+ 14 %
machine 2	312 kWh	443 kWh	+ 131 kWh	+ 30 %
machine 3	332 kWh	455 kWh	+ 123 kWh	+ 27 %
machine 4	337 kWh	330 kWh	- 7 kWh	- 2%
Differences between machines 1 to 4	**49 kWh**	**127 kWh**		

Apart from a possible differentiation between the machines, the difference between the consumption values in the Eco and the 'automatic' programmes is quite striking. Assuming 280 test cycles, the average energy consumption of machine 2 in the 'automatic' programme is 131 kWh higher as in the Eco programme while in machine 4 it is 7 kWh lower.

Consumers may be totally mislead by purchasing a good rated dishwasher according to the Energy Label classification and using this appliance in the 'automatic' programme later on. It seems that for some manufacturers only programmes included in the energy labeling scheme are optimized regarding their energy consumption. But as 'automatic' programmes are getting more and more popular they should be optimised as well and this is more likely to happen, if these programmes are included in a new version of the Energy Label.

Conclusion and outlook

During this study, the attempt was made to develop a new consumer-relevant test method for 'automatic' programmes. It should focus more on the real-life usage conditions of a dishwasher, on the one hand, and allow an increased differentiation of household dishwashers, on the other hand. A first step to increase the consumer relevance during dishwasher testing was taken during the revision of the 3rd ed. IEC 60436 with the newly developed load, the new detergent and the combined cleaning and drying evaluation. Complementarily, the test procedure for 'automatic' programmes focuses on the diverse usage conditions, beginning with a nearly empty to a fully loaded machine with different soil levels. The described method provides the possibility to assess average performance and consumption values of different load and soil levels combined with a high applicability and the possibility to test ten scenarios in one week. Even though the day to day practice in a performance lab has to be restructured and a single working day gets slightly longer the additional burden is limited. The emphasis on reduced load and soil levels challenges the currently existing 'automatic' programmes and reveals big differences between the programmes and machines tested concerning the average values and in the adaptation to different input parameters. The approach developed presents a great opportunity to further lower the consumption values of dishwashers if the Eco and the 'automatic' programme become part of the Energy Label in future. A first step into this direction has already been taken due to the implementation of the test procedure for 'automatic' programmes as an informative annex in the 4th ed. IEC 60436. Looking into the future, the informative annex should be changed to classify the approach developed as a normative test procedure. Additionally, the attention of the decision-making people within the European Commission should be drawn to the discrepancies between the current test and labelling conditions, and the consumer behaviour. Consequently, an alternative labelling approach which includes the results of tests of 'automatic' programmes could be developed. This may serve as an impulse for many manufacturers to incorporate the actual usage conditions seen in consumers' homes and the wish for low consumption values under these conditions even more.

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Heat Pump Tumble Driers: New EU Energy Label and Ecodesign requirements in Europe, MEPS in Switzerland, Initiatives in North America

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Abstract

Electric laundry drying is becoming increasingly popular in European households. Therefore, promoting efficient tumble driers[1] is essential to limit the increase in household energy consumption. Tumble driers with an integrated heat pump use only 50% of the energy a conventional electric condensing tumble drier uses. This year the European Union (EU) has introduced efficiency measures for tumble driers: since June 2013 the new EU energy label for driers is mandatory, and from November 2013 the Ecodesign regulation will apply, which contains requirements on the energy efficiency and condensation.

This paper will give an overview on Best Available Technology (BAT) in Europe according to the online search tool www.topten.eu for the most efficient drier products. This will allow for interesting conclusions including: Have the top classes of the EU energy labelling scale been designed appropriately? Will the label continue to exert an incentive for the manufacturers to develop more efficient tumble driers? Are the Ecodesign requirements stringent enough?

The market share of heat pump driers in the EU varies between countries but has been steadily increasing. In Switzerland heat pump driers are a success story! In January 2012 Switzerland imposed a minimum performance requirement that effectively allows the purchase of only heat pump driers.

The United States (U.S.) is also introducing new policies to promote efficient driers, and energy efficient technologies are poised to change tumble drier market. The article will conclude with recommendations for EU and US policies.

Introduction

Drying with an electric tumble drier in Europe is becoming more and more the trend. In the US using a tumble drier is the norm. However, these appliances use a lot of energy. Condensing driers with an integrated heat pump are a highly energy efficient technology. They use 50% less energy than conventional condensing systems. Thus it is worthwhile to promote this type of tumble drier and to push its market share.

The paper will give an overview on the main technologies of tumble driers, the European situation for driers such as market share, the new EU energy label, Ecodesign requirements, and the BAT

[1] The authors use in this paper the spelling «drier» as used in the European regulations and as opposed to the American spelling «dryer».

according to www.topten.eu. The focus then turns to Switzerland, which takes a leading role in pushing the market share of heat pump driers by its minimum energy requirements for all tumble driers. Finally we will have a look at the situation of driers in North America (the U.S. and Canada).

Technology of Tumble Driers

Two Main Systems: vented driers and condensing driers

Tumble driers evaporate the moisture by blowing hot dry air through the laundry. The air is heated up by the electric resistance heating element. There are two different technologies that exist to remove the evaporated water [1]:

1. Air vented driers (open systems): Blow the exhaust air (initially air from the room) outdoors and cause disturbing smells, steam and noise at the external outlet.

2. Air condensing driers (closed systems): Room air is cooling down the warm damp air from the wash by a heat exchanger and thus condensing the moisture.

Heat pump driers cut energy consumption by 50%

Heat pump driers are condensing driers which integrate a heat pump. Warm, damp air flows out of the laundry drum into the evaporator, where the air is dehumidified and the warm air returned to the drum.

Heat pump driers consume only about half of the electricity of conventional condensing driers. This makes them a highly efficient alternative to conventional systems. However, within the group of heat pump driers the energy efficiency varies quite a bit [2]. Due to the low temperatures heat pump driers treat clothes with care.

Heat pump driers have the lowest life cycle costs

As shown in Figure 1 heat pump driers have the lowest life cycle costs and from a life time investment perspective thus they should be the only choice. On the other hand, as also shown in the Figure 1, they (still) have a higher purchasing price than conventional driers, which might be a purchase barrier especially for consumers from struggling economic countries. Another aspect of heat pump driers that must be noted, the cycle time in general is longer than with conventional condensing driers.

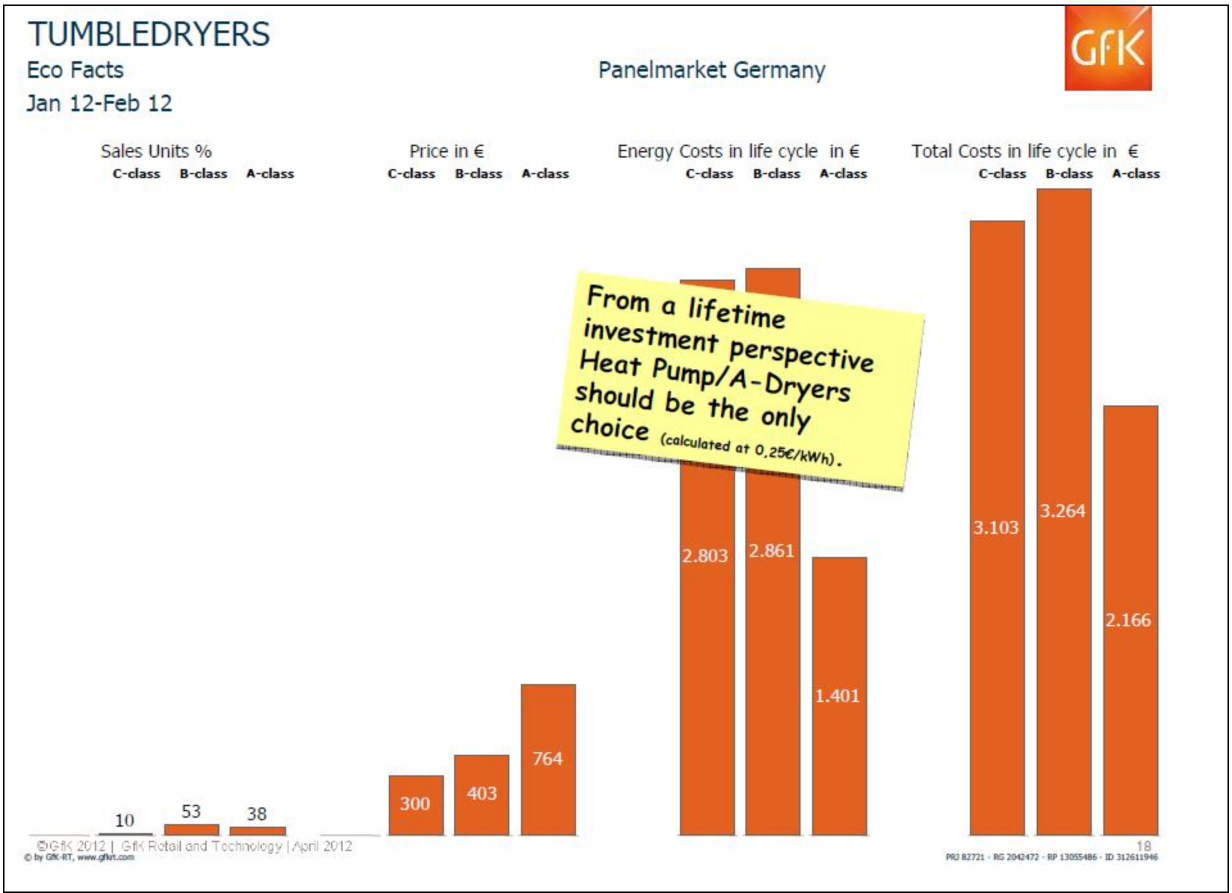

Figure 1: Tumble driers. Eco facts. January – February 2012. Panelmarket Germany. Outer left: Sales Units % C-class to A-class; Left: Price in Euro C-class to A-class; Right: Energy Costs in life cycle in Euro C-class to A-class; Outer right: Total Costs in life cycle in Euro C-class to A-class. (Source: GFK 2012 (Anton Eckl): Home Appliances – Markets with Strong Fundamentals).

Market situation of Tumble Driers

In Europe, heat pump driers are gaining market share

The market penetration of household tumble driers in Europe is steadily on the rise. Four million tumble driers were sold for residential use in Europe in 2010. The stock is estimated to be about 54 million appliances. However, the level of market penetration is uneven across European countries. For example, more than 60% of Dutch homes have tumble driers, while they appear in less than 20% of Italian homes. The dominant tumble drier technology in Europe still is conventional condensing [3].

In general it can be said, that heat pump driers are gaining market share in Europe. However, the sales share of the energy efficient alternative «heat pump driers» varies in the EU between countries. Concerning the market share of heat pump driers Switzerland is leading (for details see chapter below), but it is also high in Germany, Austria and Italy (around 40%).

In 2012, around 90 residential heat pump drier models from 18 different manufacturers were available on the European market [4].

80% market penetration of tumble driers in North America, but no heat pump driers on the market yet

In North America, dryers have reached market saturation and can be found in over 80% of U.S. and Canadian homes [3]. Recent laboratory research in the U.S. has documented that European HP driers use only half (50%) of the electricity of conventional, vented (non-condensing) US driers.

However, despite these potential energy savings, no HP driers are currently sold on the North American market and consumer and retail awareness is virtually non-existent. The Super Efficient Dryer Initiative (SEDI) is working to bring more efficient driers to the U.S. and Canadian markets [3], [5]..

Regulations in Europe

New EU Energy Label for Tumble Driers since June 2013 is mandatory

After a transition period of one year, where the old [6] and the new EU energy labels [7] could co-exist, the new EU energy label is now mandatory since June 2013. Revisions to the label include:

- Introduction of the energy efficiency classes A+, A++ and A+++: With the old EU energy label, all heat pump driers were placed in the energy efficiency class A. This although within the group of heat pump driers there exist considerable differences concerning their energy efficiency. The EU was aware of this fact and designed a new EU energy label for tumble driers. The introduction of the energy efficiency classes A+, A++ and A+++ was made to allow the distinction between more and less efficient heat pump driers. With the new EU energy label the classes A to A+++ are all reserved for heat pump driers.

- Introduction of the Energy Efficiency Index (EEI): With the old EU energy label the energy efficiency classes were based on the energy consumption (kWh) per kg of laundry. The new EU energy label calculates the EEI in a different way. The base for the calculations are for 160 standard cycles which take into account the energy consumption at full and partial load, left-on/off-mode and programme (calculation details see Annex II of [8]).

- Introduction of the «condensation efficiency»: With the new EU energy label a classification for the condensation efficiency was also introduced. The classes range from A (most efficient) to G (least efficient). This parameter is key because low condensation efficiency can lead to humid rooms and the need for additional room drying equipment and therefore an increase in the need for electricity consumption.

- Declaration of the cycle time: It is declared how many minutes the drying cycle lasts.

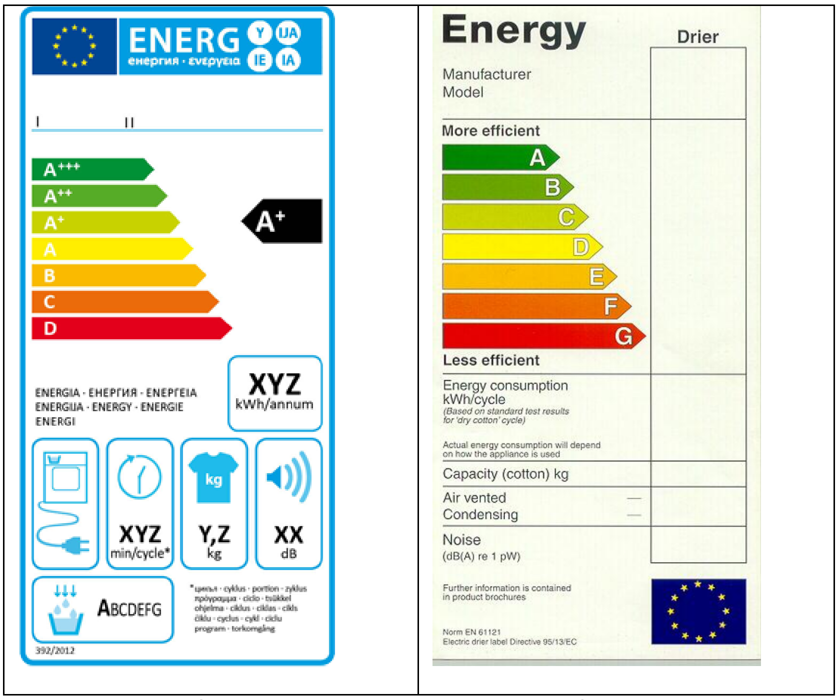

Figure 2: Left: New EU energy label for tumble driers (mandatory since June 2013). Right: Old EU energy label for tumble driers.

Ecodesign Requirements for tumble driers from November 2013

According to the Ecodesign regulation following the Minimum Energy Performance Standards (MEPS) will be required for condensing driers [8]:

	Energy Efficiency Index EEI	Condensation Efficiency
From November 2013 (Tier 1)	< 85 (equals class C and better)	> 60% (equals class D and better)
From November 2015 (Tier 2)	< 76 (equals class B and better)	> 70% (equals class C and better)

Table 1: Ecodesign requirements for condensing driers [8].

As Table 1 shows, condensing driers with class D and below will be phased out in 2014, from 2016 on condensing driers with class C and below will be phased out[2]. In other words: non-efficient appliances with a class B (they have no heat pump) will be available on the market in the future.

Until 2016 it will be allowed that up to 40% of the moisture can be expelled into the room (condensation efficiency of 60%), from 2016 on only a range up to 30% will be allowed.

Best Available Technology (BAT) of Tumble Driers on the European Market

www.topten.eu gives an overview on the Most Energy Efficient Tumble Driers in Europe

An overview of the most energy efficient tumble driers available on the European market is presented by the Topten site «Best Products of Europe» www.topten.eu [2, for Topten see box below].

In order to be listed on www.topten.eu, tumble driers must meet the following selection criteria (July 2013):

- Energy efficiency: A++ or A+++ according to the new EU energy label.
- Condensation efficiency: B or A according to the new EU energy label.

As Figure 3 shows, best performing models on www.topten.eu use between 172 kWh to 259 kWh of electricity per year (according to the declaration of the new EU energy label).

- The best EEI is 23.2.
- The threshold for A+++ is 24.
- The two 7 kg appliances reach both the energy efficiency class A++. One of them reaches the condensation efficiency class A, the other class B.
- From the ten 8 kg models, three models reach the energy efficiency class A+++, whereas two models are placed in the condensation efficiency class A, the other one only reaches class B.
- Seven 8 kg models reach the energy efficiency class A++. Three of them are classified A concerning the condensation efficiency, four models are places in the condensation efficiency class B.

[2] Class C vented driers will remain on the market in tier 2, due to a different Energy Efficiency Index EEI calculation formula.

- The three models with a capacity of 9 kg all reach the energy efficiency class A++ and the condensation efficiency class A. The drying time at full load reaches from 145 minutes to 200 minutes.

Topten will add more models as soon as the data is available from the manufacturers. Topten also will strengthen the criteria according to the development of the market.

Brand	Siemens	BEKO	AEG	Siemens	Siemens	Siemens	Brandt
Model	WT48Y7W1	DPU 8306 GXE	T97689IH T97685IH	WT48Y701	WT48Y731	WT48Y781	BFD82CH
Electricity costs (€ 15 years)	387	396	398	479	479	479	490
Capacity (kg)	8	8	8	8	8	8	8
Drying time (min) full load	187	174	188	186	186	186	180
Energy class	A+++	A+++	A+++	A++	A++	A++	A++
Energy (kWh/year)	172	176	177	213	213	213	218
Condensation class	B	A	A	B	B	B	A
Efficency Index	23.2	23.3	24	28.4	28.4	28.4	29
Countries available	on demand	on demand	DE / on demand	on demand	on demand	on demand	CH / on demand

Brand	Gorenje	Gorenje	Electrolux	AEG	Electrolux	BEKO	AEG	AEG
Model	D 8565 H	D 7565 NA/NB D 7665N	EDH3498RDL	T59880	EDH3497RDW	DPU 8305 XE	T86589IH3	T86594EIH
Electricity costs (€ 15 years)	490	448	583	477	583	522	526	583
Capacity (kg)	8	7	9	7	9	8	8	9
Drying time (min) full load	180	155	165	155	180	145	170	200
Energy class	A++	A++	A++	A++	A++	A++	A++	A++
Energy (kWh/year)	218	199	259	212	259	232	234	259
Condensation class	A	A	A	B	A	A	B	A
Efficency Index	29.2	29.6	30.3	30.7	30.8	31.1	31.8	32
Countries available	on demand	on demand	SE / on demand	DE / on demand	SE / on demand	on demand	DE / on demand	DE / on demand

Figure 3: Screenshot www.topten.eu: the most efficient tumble driers for residential use on the European market (July 2013), 7 kg, 8 kg and 9 kg capacity, energy consumption as declared at 60% initial moisture (according to EN 61121:2005).

Topten

International online search tool for the most energy efficient products on the market

Topten is an international online search tool which presents the most energy efficient products on the market such as household appliances (e.g. heat pump driers), office equipment, consumer electronics, building components, lamps and cars. It aims to accelerate market transformation towards energy efficient products, while creating a dynamic benchmark for the most efficient technologies. The selection criteria are described transparently. They are primarily based on the EU energy label, but depending on the product group additional criteria may be required. Topten is neutral and independent from manufacturers.

topten.info

Topten is online in Europe, China and the U.S.

The first Topten site appeared in Switzerland in 2000 (www.topten.ch). Since then it has travelled the world and is online in 18 European countries, China (www.top10.cn) and the U.S. (www.toptenusa.org).

Best Products of Europe on www.topten.eu

The «Best Products of Europe» are presented on www.topten.eu. The site also formulates recommendations for EU policy makers.

topten.eu

Success Story of Heat Pump Driers in Switzerland

100% market share of heat pump driers in 2012

In Switzerland, the sales share of heat pump driers has steadily risen since 2004. Figure 4 shows that heat pump driers (class A, green bars) reached a market share of around 25% in 2009, 32% in 2010, and 47% in 2011. In 2012 the market share went up to 100%. This is due to the introduction of the Swiss Energy Regulation for tumble driers [9].

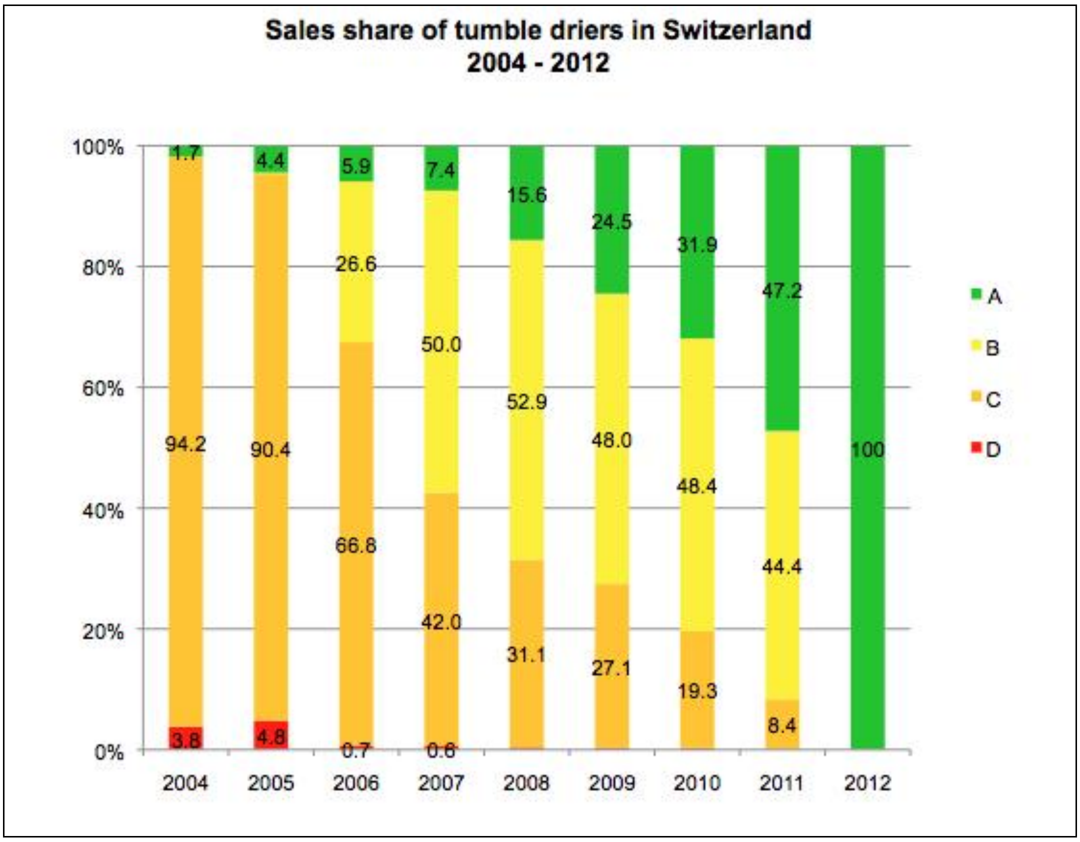

Figure 4: Sales share of tumble driers in Switzerland 2004 – 2012. Energy classes according to the old EU energy label [6]. Class A (green bars) are heat pump driers. (Source: [10])

Swiss Energy Regulation only allows heat pump driers on the Swiss market

In the framework of the Swiss Energy Regulation [9] Switzerland introduced Minimum Energy Performance Standards (MEPS) for tumble driers. This allows only for the sale of heat pump driers on the Swiss market. The requirements have been in force since January 2012. In other words, non-efficient tumble driers are completely banned from the Swiss market. This also explains why the market share of heat pump driers rose to 100% in 2012 (see Figure 4).

With its strong requirements, Switzerland is a pioneer and is leading the way with transforming the market. The success of this was in part due to the pressure by Topten and partners from Swiss environmental organisations, the city of Zurich and Zurich's utility (ewz), who closely worked together to promote and push the market introduction of heat pump driers in Switzerland (e.g. by rebate programs).

Feedback from manufacturers and consumers is positive!

The stringent requirements for tumble driers in Switzerland showed its first impact:

- The requirements work well for the manufacturers: Although the number of drier units sold in Switzerland has come down by 5%, the turnover increased [10]. Thus, there was no economic disadvantage for the manufacturers.
- The requirements are great for the consumers: heat pump driers yield high savings on their electric bill.

Initiatives in North America

SEDI is in the works to bring heat pump driers to the market

The Super Efficient Dryer Initiative SEDI, launched in 2010 by the New Jersey Clean Energy Program, brings together drier manufacturers, government agencies, utilities, and appliance retailers in the U.S. and Canada to promote the introduction of new, energy efficient and advanced tumble driers into the North American market. Since its launch, SEDI sponsorship has expanded to include thirteen energy efficiency programs across the U.S. and Canada [11].

A testing program for heat pump driers has been carried out

Programs and governments must have high-quality data on the energy savings that can be expected from heat pump technology before providing this support in North America. SEDI benefits from European experience and has tested the energy consumption of currently available European heat pump driers to North American conventional electric dryers to better understand the potential for energy savings if this technology were introduced into North America [12].

Main findings are:

- European heat pump driers use only 40-50% as much energy as North American conventional driers to dry the same amount of laundry.
- But also European heat pump driers take twice as long to dry a load of laundry as North American conventional driers.
- Further modifications to the new DOE test procedure, including the use of a test load that more closely represents real-world clothing, are needed to more accurately predict March 2013 actual drier energy consumption.
- The recently proposed 2013 revisions to the DOE clothes drier test procedure include automatic termination – a significant improvement from the current 2005 test procedure.

Energy labels for tumble driers are in preparation

Due to the lack of more efficient technology options on the North American tumble drier market, tumble driers in the U.S. have never carried energy efficiency labels. The ENERGY STAR programme has not covered tumble driers yet, and the U.S. Federal Trade Commission has not implemented an Energy Guide label for this product group [3]. The only North American energy label for driers is the EnerGuide label which is issued by Natural Resources Canada for products sold there. However, the situation with labels is about to change.

ENERGY STAR Emerging Technology Award

In 2012 the EPA announced the ENERGY STAR Emerging Technology Award for Advanced Dryers. The Emerging Technology Award is a relatively new initiative for ENERGY STAR which recognizes new, promising energy efficient technologies which are not yet established on the market. On June 12, Samsung Electronics became the first manufacturer to receive the Emerging Technology Award for Advanced Dryers for their DV457 model. In order to meet the requirements of the Award, Samsung's drier must use about 30% less energy than the average conventional US drier, and be available for sale in the U.S. Although the expectation was that Award winning driers would likely use heat pumps or other significantly different technologies, the Samsung DV457 is a vented, resistance electric drier that uses improved controls and heat and air flow modulation to reach the Emerging Technology Award efficiency target.

Heat pump driers are not yet adapted to the needs of the North American market

In North America appliances are quite different than the European ones. For example, in the U.S. the voltage is 110 Volt (Europe: 230 Volt), the frequency is 60 Hz (Europe: 50 Hz), drier size is slightly larger although the capacity (of clothes than can be dried) are similar compared to Europe (see Figure 5). The programme duration of drying cycles also tends to be much shorter than in Europe.

The challenge for SEDI over the next two years is to help reconcile the desire of North American energy efficiency programme providers for a new technology with significant savings and the desire of the appliance industry, the ENERGY STAR programme and possibly also North American consumers for more modest, interim steps on the path to market transformation. Any successful super efficient drier for North America must be designed for the local market, and laundering habits.

The US Environmental Protection Agency (EPA), which administers the ENERGY STAR programme, has released a preliminary draft of a technical specification for a U.S. (potentially also Canadian) ENERGY STAR label for clothes dryers. This draft proposes minimum efficiency requirements that are about 15% above the average for current, conventional, vented electric tumble driers sold in the U.S. This level would also be significantly less efficient than a typical European HP drier.

Figure 5: Drum size difference: European drier (left) and North American (right) drier [12].

No rebate programs for tumble driers yet

Until now no rebate programmes have been carried out to promote high efficiency tumble driers. Feedback from some of the utilities in the U.S. is that a barrier to entry for heat pump driers is that European models are too small in size and would be too expensive to purchase compared to current drier models.

Conclusions and Recommendations

Europe

EU Energy label

In Europe, it is foreseen that the energy classes A to A+++ of the EU energy label are reserved for heat pump driers. This makes it possible a differentiation between efficient and less efficient heat pump driers. It is no surprise that there are already A++ driers available at the time of the introduction of the new EU energy label (see www.topten.eu). But some have already reached the A+++ class indicates that the thresholds of the classes seem to be too low. Some heat pump driers also already meet the top class for condensing efficiency A. When designing new classes the best class should be kept empty for future developments. Otherwise a result might be that manufacturers do not have enough incentive to improve the technology.

Therefore it is recommended that the EU energy label for tumble driers should be updated in a timely manner to reflect the fast changing market. The new energy efficiency classes are weak, it is necessary to revise the EU energy label as soon as possible to facilitate further improvements. The top classes should then be held empty for future technical developments.

Ecodesign requirements

The requirements for tier 1 and tier 2 of the Ecodesign regulation for tumble driers do not seem ambitious enough. Non-efficient tumble driers will also be allowed on the market in the future. The requirements for the condensation efficiency also seem to be weak, taking into account what is already technically possible (class A and B, see the BAT according to www.topten.eu).

Therefore it is recommended that within the next revision of the Ecodesign regulation the future MEPS be more stringent for tumble driers regarding energy efficiency as well as condensation efficiency. The goal should be that only best performing appliances – heat pump driers – shall be allowed on the European market.

Good example: Switzerland

With the market for tumble driers having changed significantly in Switzerland due to the introduction of the Swiss MEPS, the feedback from manufacturers and consumers has been positive. The market stayed stable, sales are going well and considerable energy savings are being realized.

The example of Switzerland shows, that the introduction of stringent requirements for tumble driers is possible and brings a win/win-situation. The example should be followed by the EU.

North America

ENERGY STAR

Market push of existing tumble drier technology with ENERGY STAR is expected to bring efficiency improvements of about 15%. It now appears that improved conventional tumble driers will be capable of reaching ENERGY STAR. In the future, the label should be designed to set a more ambitious efficiency target. Improvements of test standards, labels and more research are important to enable a smooth development of new technologies.

ENERGY STAR Emerging Technology Award

The ENERGY STAR Emerging Technology Award brings an improvement of about 30% over conventional North American driers. It is recommended that future awards be designed to only be reached by driers with heat pump level efficiency.

Market introduction of heat pump driers

The current market environment in North America lacks market pull for heat pump driers. If there are no additional subsidies or market support for driers at the 50% efficiency improvement level or higher, there will be little reason for drier manufacturers to introduce heat pump or other super efficient technologies to the North American market.

Therefore market introduction of heat pump driers needs special efforts. Policies are needed to give manufacturers incentives to develop heat pump driers adapted to North American market needs and consumer expectations. SEDI, ENERGY STAR and energy efficiency programmes are working to assist a successful market introduction, and to support the manufacturers in their endeavors. Programmes that run rebate programs should assist in educating and to successfully overcome the market barriers (e.g. higher purchase price) by promoting best performing appliances. Rebate programmes should be decided now, to enable long-term planning for the manufacturers.

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Vacuum space insulation for household appliances

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Abstract

For decades, vacuum space insulation (VSI) has been recognized as an established technology for the thermal insulation of Dewar flasks, cryogenic equipment and so on. Although it is established in these domains, VSI technology is still not widely used as a thermal insulation in such application fields as white goods, home appliances, boilers and hot water tanks, as well as industrial equipment.

The findings obtained by our recent research – supported by the Swiss Federal Energy Office (several SFOE research orders within the SFOE research program "Electrical technologies and applications") – show that VSI has great potential for such applications as mentioned above:

- VSI requires relatively little space and thus provides additional useful volume
- VSI saves a lot of energy
- VSI can also be very interesting from an economical point of view

In addition, VSI can also have functional advantages, such as significantly reduced space requirements or internal volume gains with constant external dimensions.

Our paper discusses the basics of VSI and shows the technological possibilities which it offers. Presented are spacers which are cheap to produce, which have a sum heat transfer coefficient of approx. 0.01 W/m^2K and therefore do not significantly reduce the thermal advantages offered by a vacuum.

In a first example it is shown that VSI technology is economically feasible for the thermoblock in a coffee machine, and offers the user increased comfort with significantly reduced energy consumption.

In the second example, the use of VSI for hot water boilers is discussed. With a functional model of an 80 liter boiler a reduction of the thermal losses of more than 70% is achieved, in comparison to the best commercially available model. The additional costs for the customers are redeemed within 8 years of purchase.

In a third example, the basic structure of a cylindrical refrigerator with VSI is discussed, showing that, at a slightly heightened useful volume, compared to a normal market cubic A++ refrigerator, energy savings of around 50% and higher are possible.

Principles of vacuum space insulation (VSI)

VSI (see figure 1) consists mainly of two gastight boundary plates bordering the vacuum, which edges are connected by means of a hermetic seal (edge assemblage). The shape of the boundary is arbitrary. It may be two flat, parallel plates or two arbitrarily shaped boundaries with variable spacing.

Spacers are inserted into the vacuum in order to prevent the boundary plates from being pressed together by the exterior air pressure. This measure is only necessary if the boundary plates lack sufficient stiffness. This is typically the case if the boundary plates are flat or only slightly bent.

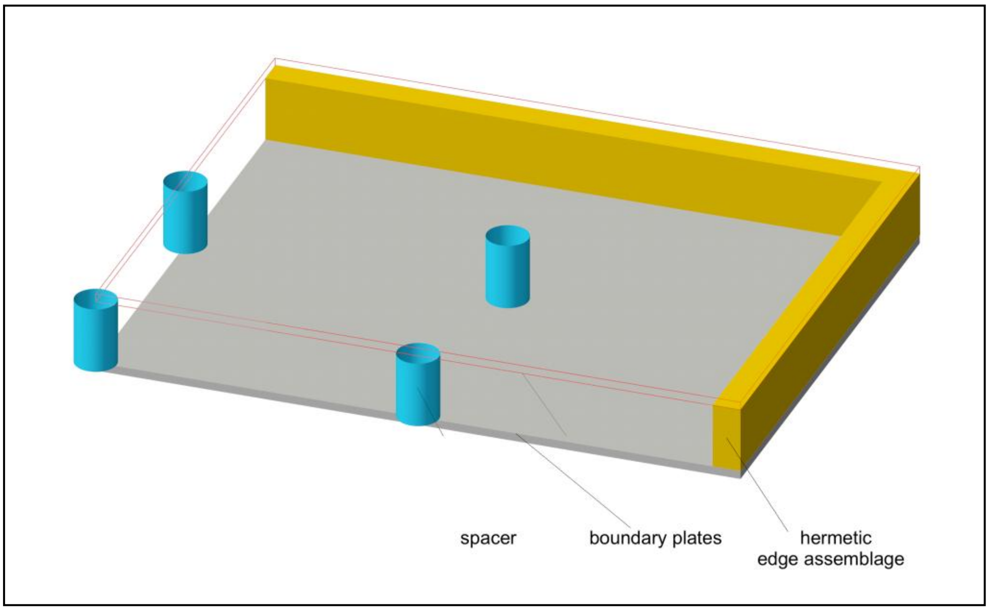

Figure 1 Schematic diagram of a vacuum space insulation (VSI)

The total heat transfer coefficient (U_t) of a VSI profile includes the three components of heat conduction through residual gas, heat radiation and heat conduction through solids in gaps and on edges:

$$(1) \qquad U_t = U_g + U_r + U_b \left[\frac{W}{m^2 K} \right]$$

U_g = U (residual gas)
U_r = equivalent U(T) (radiation)
U_b = U (solid body)

Residual gas heat transfer

References [1] and [2] contain formulas for calculating the heat conduction λ of the residual gas as a function of the pressure p, the wall spacing s and the temperature T. The heat conduction coefficient U_g [W/m^{2}K] through the gap (generated by the heat conduction in the residual gas) is decisive. It is calculated thus

$$(2) \qquad U_g = \Delta T * A * \frac{\lambda}{s}$$ whereby ΔT=1K and A=1m^2

Fig. 2 can be calculated from λ and (2) – it shows the heat transfer coefficient U_g through a vacuum gap at room temperature in dependence of pressure p and the wall spacing s.

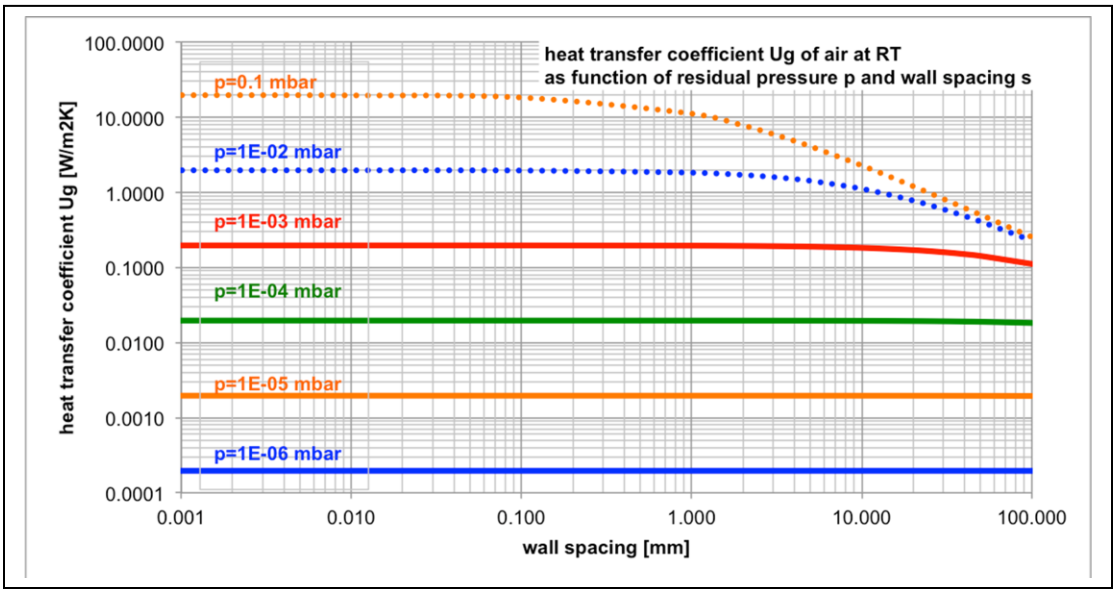

Figure 2 Heat transfer coefficient U_g of air at room temperature as function of residual pressure p and wall spacing s

For a very good thermal insulation, usually, heat transfer coefficients of < 0.1 [W/m^2K] are to be strived for. From Fig. 2 it can be seen that this can be accomplished only with a residual gas pressure of < 10^{-4} mbar. This normally means that, at the beginning of a lifespan of a VSI, a vacuum pressure of <10^{-5} mbar must be accomplished. It can also be seen that the heat transfer coefficient Ug with such a vacuum is fully independent of the wall spacing and determined solely by the prevailing residual pressure.

With this, it can be deduced that the wall spacing in a VSI can vary greatly e.g. from 0.1 mm up to 100 mm without the creation of any thermal vulnerabilities through heat conduction in residual gas. This differentiates VSI from all other known kinds of thermic insulation and offers great design freedom.

Radiation heat transfer

In addition to the direct heat transfer via the residual gas molecules in the vacuum, thermal radiation influences the quality of the insulation. Without additional measures, the thermal radiation in the vacuum gap will head directly from wall to wall and can reach very high values. The measure for the reduction of heat radiation which we have adopted for this, is the insertion of films between the two walls which delimit the vacuum gap. Structurally, it is important to ensure that these films do not touch the walls or each other (or only minimally). Helbling Technik AG ensures this with specially developed film backing.

Our detailed studies show that only inexpensive and rolled aluminum foils are accepted as suitable foils.

In the VDI heat atlas (section "superinsulation") [2], there are formulas that are used for the calculation of radiation through a sequence of n identical foils.

Fig. 3 shows the calculated equivalent heat transfer coefficients U_r with the mentioned formulas. In addition, the temperature range of some important household devices is referenced. The related interior temperature T1 can be read on the abscissa of the diagram. The exterior temperature T2, the room temperature, was assumed to be 23°C.

The Fig. 3-Fig. 2 comparison clearly shows that heat transfer by radiation U_r vs. heat transfer U_g through the residual gas (U_g = 0.002 W/m^2K @ 10^{-5} mbar) is in no way negligible.

With a vacuum gap without radiation-reducing intermediary films e.g. with most vacuum thermos bottles and mugs, the heat transfer coefficient is clearly dominated by the thermal radiation (Ur approx. 1 W/m^2K). These are represented in Fig. 3 using examples like a boiler or a coffee machine.

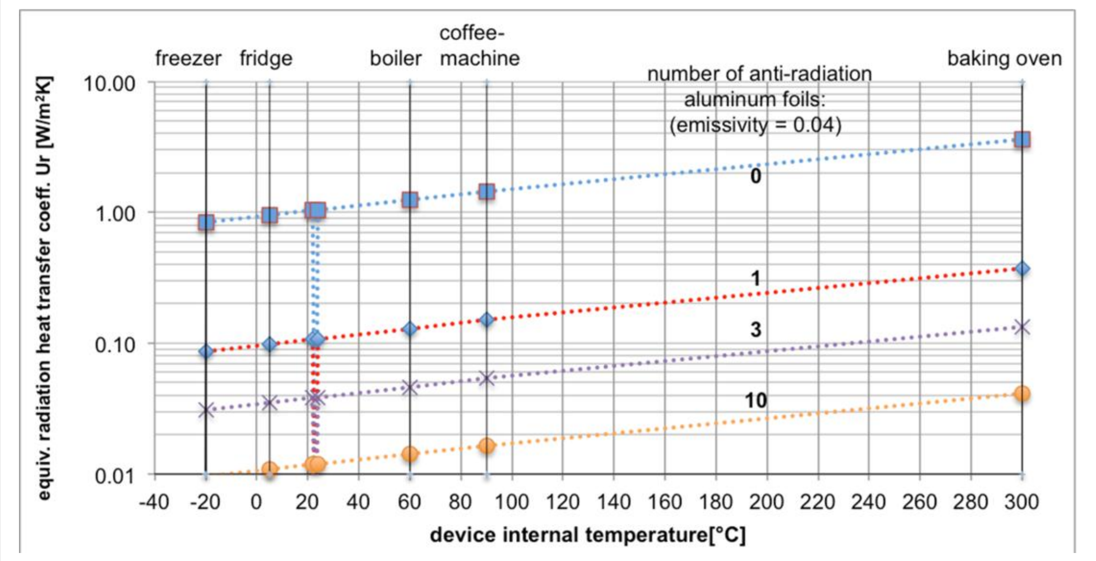

Figure 3 Equivalent radiation heat transfer coefficient U_r as function of temperature and number of anti-radiation foils

With thermos flasks, this high U_r value is acceptable, because to achieve the same U-value with conventional insulation would require e.g. an approx. 4-5 cm thick insulating sheath of expanded polystyrene or mineral wool. A similar consideration also applies with the insulation of the thermoblock of a coffee machine.

Fig. 3 also illustrates that the insertion of an individual radiation-reducing film is enough to bring about a reduction of the heat transfer coefficient by approx. a factor of 10, to approx. 0.1 W/m^2K. With the insertion of additional films, the heat transfer coefficient can be reduced by a further factor of 10 to approx. 0.01 W/m^2K.

Fig. 3 also shows that the equivalent radiation heat transfer coefficient U_r depends much on the temperature of the warm or cold internal wall of the vacuum gap. With an internal temperature increase from -20°C to 100°C the U_r increases by approx. a factor of 2; and with a further increase up to 300°C there will be recognized the additional factor of 2.5. But it is also clear that this rise in U_r can be approximately compensated with the insertion of additional radiation-reducing films.

Solid body heat transfer

Solid body heat conduction always occurs on the edge of a VSI profile, through the gastight connection of the two plates to each other. Also, in many cases, local so-called spacers are present at the interior of the VSI profile which additionally contribute to the solid body heat conduction. What we write for the total heat transfer coefficient (through solid body heat conduction U_b) is as follows:

(3) $$U_b = U_e + U_s$$

U_e Equivalent heat transfer coefficient through thermal edge effects

U_s Equivalent heat transfer coefficient of the spacers

It is obvious that a flat or slightly curved part (with vacuum gap) must include spacers in the vacuum if the two major bounding surfaces cannot have an extremely rigid profile. The air pressure 0.1 N/mm^2

(= 1 ton per m^2) would otherwise press the two boundary plates together and nullify the insulation effect of the vacuum.

The requirements for a useful spacer are clear: it must show a level of thermal conductivity that is as low as possible – at least in the vacuum – and a large compressive strength in order to minimize the required crossectional area of the spacers.. In addition, it must be able to withstand very high temperatures during the pumping, and it may not subsequently leak gas in the vacuum. With this, it is important to note that the operating temperature can reach 300°C with some interesting applications (e.g. ovens).

Helbling Technik AG has made calculations with a large number of different types of spacers and performed measurements, from which it has become clear that such approaches as plastic or steel pressure elements, slender struts made from low-heat-conducting ceramic and pressure-to-tensile-load-change braced filaments in the lateral direction of the vacuum gap are sometimes insufficient thermically, or may not be eligible due to reasons relating to mechanical or thermal stability or due to unacceptably high costs. Thus, Helbling developed spacers – and applied for a patent with them – which are cheap to manufacture and which meet all requirements.

The structure of the new development – we refer to as ball spacers – is outlined in Fig. 4. The structure is simple: a thin, resilient and flexible cover encloses a flowable filling material. Thus there is a change from pressure to tensile load – similar to a ball. This change from pressure to tensile load is known to be mechanically beneficial.

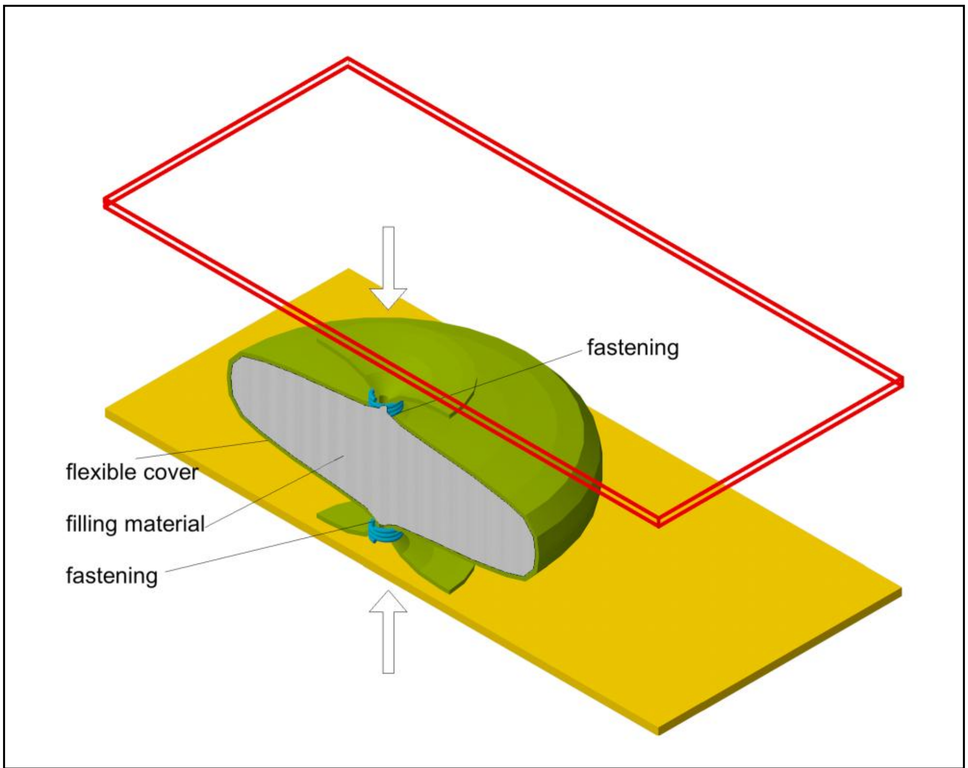

Figure 4 Schematic diagram of a ball spacer

When implementing the principle, it must first be ensured that the flowable filling material conducts only very little heat, and can withstand high temperatures and pressures. Such material is available with e.g. granular fumed silica, which is known to show a thermal conductivity of only approx. 3 mW/mK at lower pressures of less than < 1 mbar.

Secondly, it must be ensured that the flexible cover material is of proper tensile strength and temperature-resistant. Furthermore, the flexible cover should also, naturally, conduct as little heat as possible, which means that the flexible cover material should be as thin as possible and show as little thermal conductivity as possible. Moreover, it must be highly gas-permeable, so that the filler material in question will be evacuated during the pumping of the VSI. Such material is available at an extremely low price e.g. in the form of so-called glass filament tubes.

The mass production of such spacers (tested in small sample series by Helbling Technik AG) can be performed in accordance with the production of sausages: The filling material is injected into the flexible cover on a quasi-continuous basis; and the flexible cover is tied and cut at appropriate intervals.

In this way, with a simple test device it is possible to e.g. reproduce ball spacers with a diameter of 8 mm and a height of 12 mm which are temperature-resistant up to at least 400°C, and which can withstand up to 2500 N of pressure per spacer. The only mildly temperature-dependent thermal conductivity of such a spacer (filler material + cover) is approx. 45 [mW/mK] @ 20°C and approx. 55 [mW/mK] @ 300°C. Considering that a maximum of 49 such ball spacers is necessary per m^2 – due to the large compressive strength – this would mean a calculation of an equivalent thermal conductivity of the spacers inserted in the VSI profile (i.e. across the entire area) of ≤ 0.1 [mW/mK].

With the application of a similar approach, the equivalent heat transfer coefficient U_e resulting from the heat transfer at the edge of a VSI can also be overcome. A 10-20 µm thick stainless steel strip forms the gastight connection between the two boundary plates which border the vacuum gap. This thin strip must be supported against the air pressure on the vacuum side of the VSI which occurs with a thin body whose material shows a thermal conductivity of less than 5 mW/mK in a vacuum. In this way, a thermal conductivity of approx. 20 mW/mK can be achieved with a gastight edge seal that is, in total, approx. 10 mm wide.

Another very effective way of minimizing the conduction of heat across the edge, is the overlap principle, which involves the overlaying of adjacent VSI profiles in such a way that allows for the longest possible heat transportation through a wall that is as thin as possible. With this method, in most cases it is possible to muster structures for which the U_e contribution is almost negligible.

Total heat transfer

With the example of a VSI with 3 radiation-reducing films, 49 ball spacers, a residual gas pressure of 10^{-5} mbar and an internal temperature 90°C, Fig. 5 shows a summary of the discussed components (U_g, U_r, U_e and U_s) which contribute to total heat transfer coefficient U_t

It is clear that the components (U_r and U_g) originating from the heat radiation and heat transportation in the residual gas, at the technically interesting wall spacing range of up to 100 mm do not depend on the wall spacing and, in total, show only an equivalent heat transfer coefficient of approx. 0.05 W/m^2K.

The equivalent heat transfer coefficient U_s resulting from the 49 ball spacers depends strongly on the height of the spacers, which is determined by the wall spacing. Very good U_s values (≤ 0.05 W/m^2K) are yielded with a spacer height of only approx. 3mm. With a spacer height of approx. 10 mm the U_s is almost negligible.

The equivalent heat transfer coefficient for the thermal boundary effects U_e was calculated in 2 different ways.

The curve U_e1 in Fig. 5 results from the assumption that flat 2 m^2 VSI panels are positioned close together without overlapping, whereby, for each VSI profile, the two panels bordering the vacuum along the entire edge are welded together (gastight) with a steel band of a thickness of 20 µm; and, on the vacuum side, this steel strip is supported with a 10 mm-wide strip e.g. of pressed fumed silica. With this assumption, U_e1 forms the dominant share of the corresponding total heat transfer coefficient U_t1.

If, for the curves U_e2 and U_t2, it is assumed that the corresponding VSI profile recognizes an overlap of a width of 200 mm, the influence of the thermal boundary effects shall be greatly reduced. With this fact, it is to be concluded that much attention is to be devoted to the structure of the VSI edging.

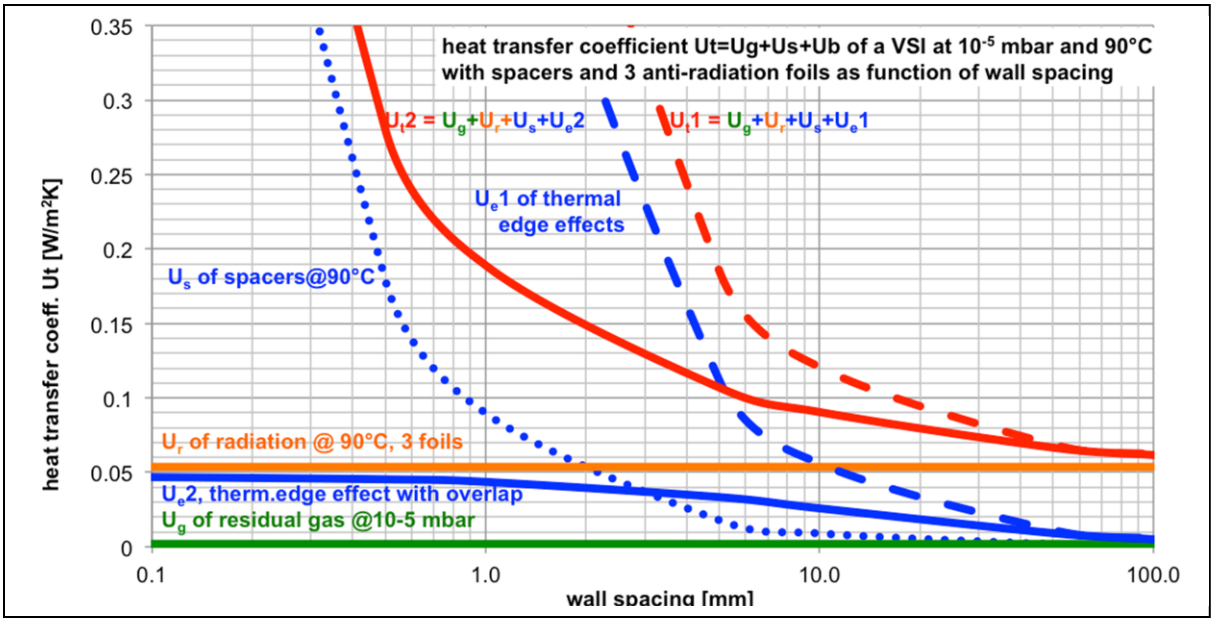

Figure 5 **Total heat transfer coefficient U_t of a VSI with spacers and 3 anti-radiation foils, at 10^{-5} mbar and 90°C, as function of wall spacing**

To illustrate how good the achievable U_t values are with the VSI in question, the insulation thicknesses s which are necessary for commercially available insulation materials of the same U value are shown in Table 1.

Table 1 **Heat transfer coefficient U_t of a VSI with different numbers of anti-radiation foils and temperatures and correspondent thickness s of customary insulation materials**

T		VSI @10^{-5} mbar		mineral wool			PU (polyurethan)		
°C		s mm	Ut W/m²K	λ W/mK	s mm	U W/m²K	λ W/mK	s mm	U W/m²K
10	1 foil	**10**	0.136	0.039	**284**	0.136	0.023	**169**	0.136
	3 foils	**10**	0.071	0.039	**541**	0.071	0.023	**322**	0.071
	6 foils	**10**	0.054	0.039	**719**	0.054	0.023	**428**	0.054
90	1 foil	**10**	0.187	0.048	**256**	0.187	0.036	**193**	0.187
	3 foils	**10**	0.090	0.048	**528**	0.090	0.036	**398**	0.090
	6 foils	**10**	0.064	0.048	**745**	0.064	0.036	**561**	0.064
300	1 foil	**10**	0.417	0.090	**216**	0.417	-	-	-
	3 foils	**10**	0.176	0.090	**512**	0.176	-	-	-
	6 foils	**10**	0.110	0.090	**818**	0.110	-	-	-

Table 1 also illustrates the dependence of the U_t values of a VSI on the temperature and the number of radiation-reducing films. It is clear that U_t increases with increasing temperature, which is mainly due to the influence of heat radiation. With this, an increase in the number of radiation-reducing films doesn't just reduce the absolute U_t value, but also the influence of the temperature.

It is clear that a VSI profile with a wall spacing s of only 10 mm and with a single radiation-reducing film in the vacuum space is enough to replace a stone wool insulation with a thickness of 200-300 mm and a PU (polyurethan) insulation with a thickness of 150-200 mm. 3 films included in the vacuum space could be enough to replace approx. 500 mm of stone wool or approx. 350 mm of PU. With the insertion of 6 films, these values would once again rise significantly.

It can be concluded from these theoretical considerations (which are supported by many measurements) that attempts to use VSI (which has been used with such products as Dewar flasks for decades) with additional products are always worth it. Helbling Technology AG has done this –

primarily in the domain of household devices – with support from the Swiss Federal Energy Office (several SFOE research applications as part of the SFOE research program "Electrical Technologies and Applications").

There follows presentation of some of the results achieved.

Application examples

Example 1: Domestic coffee machine

In the following example, we limit ourselves to (capsule) household coffee machines whose hot water is accomplished with the aid of a thermoblock. However, our investigations have shown that the results achieved with thermoblocks can be analogously transferred to instant water heaters and boilers.

Thermal losses with a coffee machine occur mainly at the hottest part – the thermoblock (unit heater). All thermal losses with other parts of the machine, on the other hand, are negligible. This means that one may limit themselves to the thermoblock as far as reduction of thermal loss (thermal insulation) is concerned.

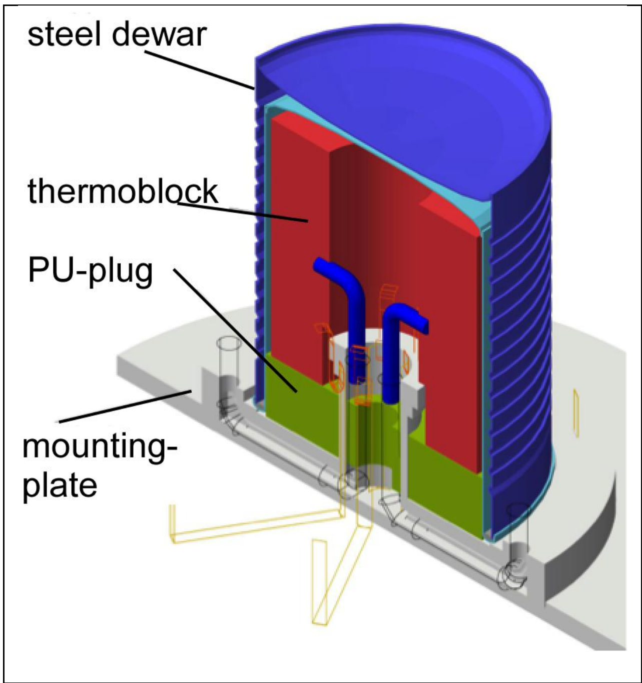

Figure 6a Schematic diagram of thermoblock within Dewar-like VSI

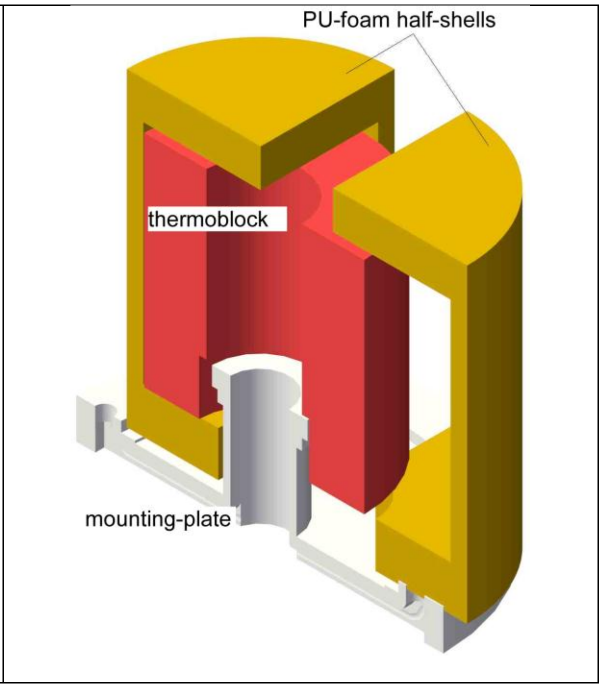

Figure 6b Schematic diagram of thermo-block within PU-foam half-shells

Helbling Technik AG has looked at various approaches regarding thermal insulation of non-insulated thermoblocks in the machines of today. With this, it was of major importance that the insulation does not increase the dimensions of the thermoblock exceeding 20 mm in diameter or 40 mm in height. Furthermore, adopting a maximum cost increase from 1$ to 2$ per coffee machine (due to the additional insulation) is valid. Finally, it has been shown that, under these conditions, only the two approaches outlined in Fig. 6 are worth pursuing (insulation of the thermoblock with a cup-type VSI – Dewar – or with PU foam).

Fig. 6a provides a detailed outline of the approach for insulation of the thermoblock with a cup-type VSI and Fig. 7a shows a photograph of an accomplished functional model. Thanks to the cylindrical shape with a small radius, the VSI profile does not require any spacers in the vacuum spacing. The height of the VSI profile is significantly greater than that of the thermal block, meaning that the open lower side of the cup underneath the thermal block (with a 20 mm-thick PU plug) can be insulated.

All leads and pipes are connected to the thermoblock via the PU plug. Thermally, this doesn't just provide insulation of the lower side, but also accomplishes the overlapping principle referenced in the theoretical part. With this, the heat from the thermoblock on the approx. 90°C-heated inner wall of the VSI cup travel 20 mm through the inner wall of the cup, which is only 0.1 mm thick, before it gets to the surroundings. With this, thermal losses are drastically reduced.

Figure 7a Thermoblock within dewar-like VSI on mounting-plate of domestic coffee-machine

Figure 7b Thermoblock within 10mm thick PU-foam insulation

The above required conditions are satisfied with the structure indicated in Fig. 7a: the diameter increase caused by the VSI is only 10mm. The increase of the height the accomplished sample pattern is still approx. 80 mm, but it can be reduced to approx. 30 mm without any problems. As far as the expected additional costs are concerned, initial offers have been made available to Helbling. With this it is to be expected that the upper limit of max. 2$ can be undercut with a corresponding number of pieces.

Fig. 6b and 7b show the insulation of the thermoblock with 10 mm PU foam, with eligible additional costs of less than 0.5$. The approach with 2 half-shells allows for a very easy insulation assembly whereby the thermoblock is already fixed on the base plate. Regarding the function sample, the thermoblock was injected with 10 mm-thick PU foam all around prior to the assembly.

Fig. 8 shows cooling curves (solid lines, left scale), calculated and verified by measurements, which depend on the cooling time after the heating has been switched off. The current state of the coffee machine, which keeps the temperature of the thermoblock at approx. 90°C for 20 minutes (in the so-called auto-off state) before the heating is switched off, is indicated in black. The red curve shows the cooling with the above-described cup-shaped VSI, and the blue curve shows that recognized with the 10 mm PU insulation. With this, in both cases it is assumed that the heating will switch off without any kind of delay pending.

The dotted curves show, accordingly, the heating times (timescale right diagram side) which are required after the expiry of a certain cooling time in order to heat the thermoblock from the correspondent cooling temperature to a working temperature of 90°C.

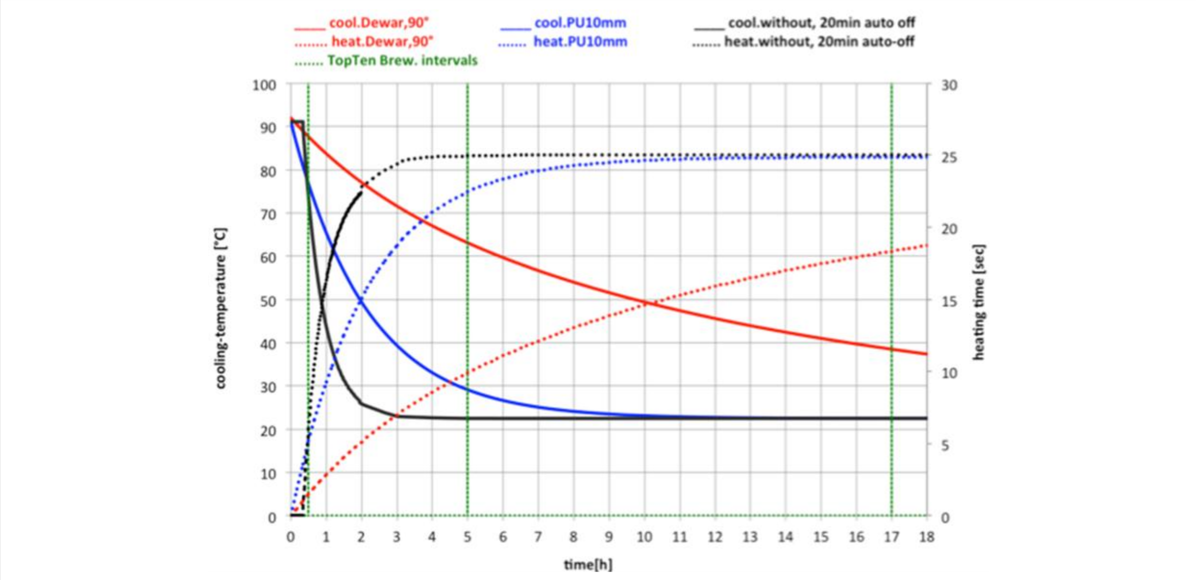

Figure 8 Cooling down temperatures (solid lines, left scale) and heating up times (dotted lines, right scale) as function of cooling down time

The differences are clear. In the current state, without insulation the thermoblock cools to approx. room temperature within 2 hours despite a holding time of 20 minutes. With a 10 mm PU insulation it is still 50°C warm after this cooling time, and with VSI it still has a temperature of 77°C. Naturally, the corresponding heating times are also shorter. Without insulation, the heating time is approx. 24 seconds after 2 hours; with a 10 mm PU insulation profile it is 15 seconds and with VSI it is only 5 seconds.

With this, with VSI it is possible to have a coffee machine which requires absolutely no standby energy, without any loss of comfort to the user. After the coffee has been dispensed, the machine turns itself off fully independently so it can then heat up again automatically when a new coffee capsule is inserted.

The corresponding energy savings can be calculated with the help of the curves shown in Fig. 8. We have done this in Table 2 according to the TopTen measuring guidelines [3]. As a reference we used a moderately good, commercial coffee machine, whose annual consumption is, according to TopTen, 42 kWh/a. (A similar comparison according to the Swiss energy label still shows significantly higher savings than those listed in Table 2 according to TopTen).

According to TopTen, the energy consumption is calculated as follows: 2*3 cups (120 g) are brewed per day (within one hour), and one cup is brewed after 0, 30, and 60 minutes. The intervals between the hours in which the 3 cups are brewed, are 5 hours and 17 hours.

With this, the saved energy SE is calculated as follows

(4) $$SE\ per\ day = SE(17h) + 2*SE(0.5h) + SE(5h) + 2*SE(0.5h)$$

(5) $$SE\ per\ year = 350 * {}^{SE}\!/_{d}$$

In addition, we have estimated the efficiency level of the coffee machine, which is calculated by comparing the theoretical minimum energy which is necessary for heating up the water (total 6*120g) to 65°C. The theoretical minimum is:

(6) $$350*6*9.13Wh = 19.2\ [\mathrm{kWh/a}];\ 350\,{}^{d}\!/_{a};\ 6\,{}^{cups}\!/_{d};\ 9.13\,{}^{Wh}\!/_{120g\ water}$$

During the calculation, it is to be noted that the reference device maintains the brewing temperature for 20 minutes, and only then does it switch the heating off. With the insulated variants, on the other hand, it is assumed that the heating is fully turned off immediately after the brewing process has been fully completed i.e. a "Zero Standby Energy" strategy is adopted.

Table 2 Comparison of both insulated devices with the reference device

Insulation type	Saved energy per day [Wh]	Saved energy per year [kWh]	Resulting energy consum-ption [kWh/a]	efficiency level	Estimated insulation-related additional costs CHF	Additional construct. height [mm]	Additional Ø [mm]
Nothing	0	0	42.0	45.7%	0	0	0
PU 10 mm	33.5	11.7	30.3	63.3%	≤ 0.5	20	20
Dewar	46.6	16.3	25.7	74.6%	≤ 2.0	30	10

These results are self-explanatory: the use of VSI in coffee machines appears worthwhile.

Example 2: Domestic storage water heater

Fig. 9a and 9b show the schematic diagram and photography of a VSI developed and evaluated by Helbling Technik AG – with support from the Swiss Federal Energy Office (SFOE research orders within the SFOE research program "Electrical technologies and applications") – for an 80-litre hot water boiler.

A design was selected where the hot water boiler was inserted in a tubular, double-walled structure with an open top and bottom, where the gap between the two walls of the pipe was evacuated at ≤ 10^{-5} mbar. Thanks to the cylindrical form of the VSI and the corrugated outer wall, even with this kind of design no spacers in the vacuum spacing are necessary in order to ensure mechanical stability against air pressure and other forces.

The thickness of the external wall of the pipe is 0.5 mm. With the interior wall: a wall thickness of 0.1 mm is theoretically sufficient; however, in the functional model, for manufacturing reasons it was 0.2 mm. The external diameter of the domestic storage water heater is 0.46 m and it has a height of 1 m (see Figure 9).

The two pipe walls are directly welded together at the ends of the pipe. For this reason, the overlap principle was used to achieve good thermal conditions. The vacuum pipe is, in total, 400 mm longer than the height of the actual hot water boiler, and 200 mm-thick PU plugs are inserted in both ends of the pipe. Thus, an equally long thermal conduction route through the interior wall of the pipe (only 0.2 mm thick) ensures desired good thermal conditions.

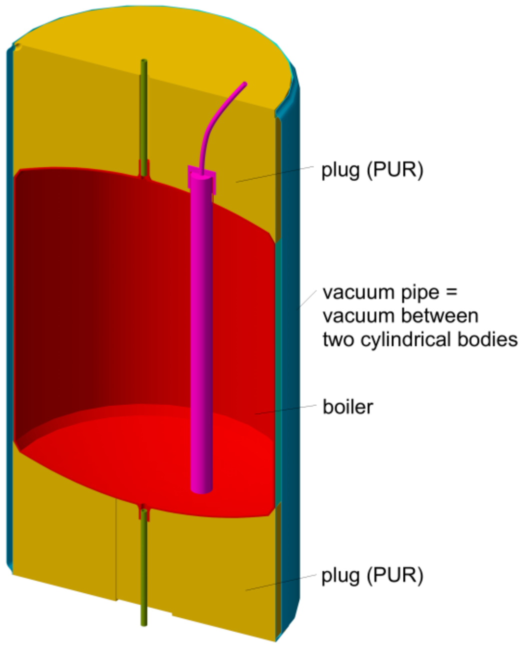

Figure 9a Schematic diagram of storage water heater with VSI pipe

Figure 9b Functional model of VSI duct for 80 liter storage water heater

Two types of functional models were built: one without radiation-reducing film in the vacuum spacing, and one with a quasi-free floating film in the entire vacuum spacing.

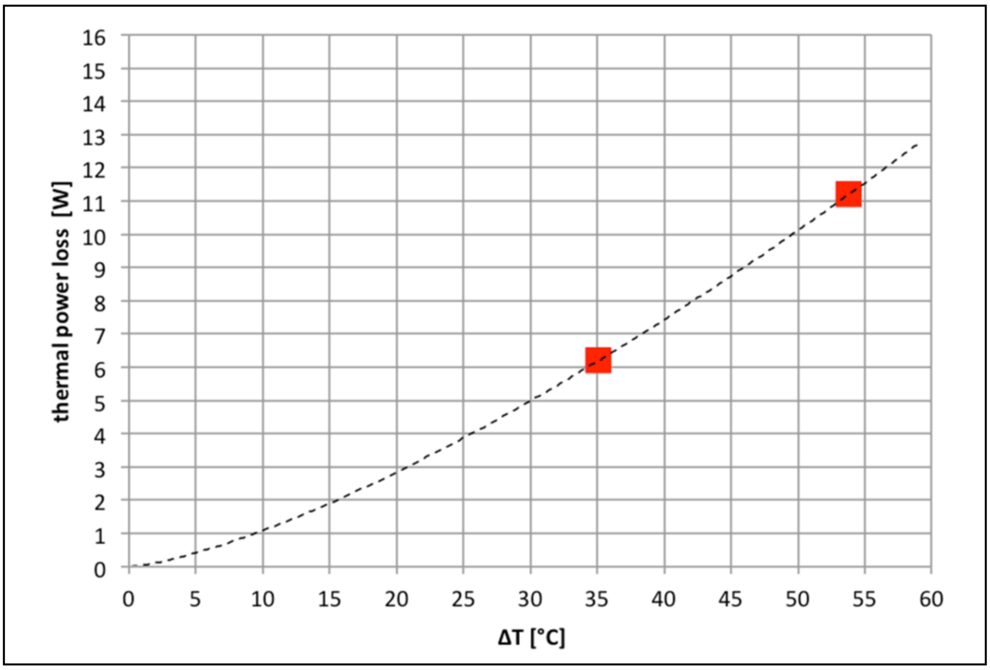

Figure 10 Power loss of VSI for 80-liter storage water heater with 1 anti-radiation foil as function of ΔT

Fig. 10 shows the result of a measurement with the test construction with the VSI profile containing radiation-reducing aluminum foil. During the measurement, a heating power and power dissipation equilibrium was kept with a ΔT of 35°C and 54°C.

Table 3 shows the calculated thermal losses (taken from the measurements), compared with those of the 80-litre hot water boiler that is currently the best on the market (according to TopTen).

Table 3 Calculated and measured thermal power loss of functional models of VSI for 80-liter storage water heater

design	size of PU mm	vacu. space width mm	foil count	calculated loss analytic kWh /a	calculated loss FEM kWh /a	loss measured kWh/a	loss reduction kWh /a	loss reduction %
best on market, PU-insulation	85	-	-	240				
function. model, without foil	duct-ends: 200	10	0	188	182	184	56	23%
function. model, with 1 foil	duct-ends: 200	10	1	64	67	65	175	73%

It can be seen that the functional model, even without radiation-reducing aluminum foil (with a saved lost energy rating of 23%) is better than the state of the art boiler on the market.

The sample with a radiation-reducing film, with a 73% loss reduction, indeed shows very good values.

The costs were estimated for a possible series production of an 80-litre boiler with such a VSI type. The additional costs of such a boiler with a VSI, when compared with the costs of the PU-insulated boiler that is currently the best on the market, amount to less 300 $ in sales. This means that the necessary additional investment would be recouped within 8 years with the current energy prices.

Example 3: Domestic refrigerator

Due to the space constraints of this publication, the "domestic refrigerator" example cannot be discussed in detail here and only the most important results can be presented.

Two different approaches for implementing a refrigerator with VSI were investigated: on the one hand a cylindrical refrigerator and on the other hand a refrigerator with the standard cubic shape.

Potential structures using VSI were devised for both approaches and detailed thermal calculations were carried out. These calculations were verified using a prototype of the cylindrical refrigerator. The possible usefulness of a cylindrical refrigerator depends to a large extent on whether or not it is possible to build one in such a way whereby the shape-based loss of usable volume is fully compensated by a thinner wall (compared to the conventional cube-form A++ refrigerator).

Appropriate calculations show that this is achieved when the full thickness of the wall of a cylindrical refrigerator with VSI is approx. 15-16 mm. This can be achieved with VSI.

The greatest challenge when producing a cubical refrigerator with VSI is to build the even walls so that they can resist the air pressure with the lowest possible total wall thickness. This is possible using the spacers described above.

Table 4 shows the achievable power loss (calculated by us) of similar cylindrical and cubic VSI refrigerators with 600 mm external diameter respectively 600x600 mm external profile and 1400 mm height.

Table 4 Calculated power consumption of refrigerators with VSI compared to usual cubic A++ refrigerator

design	ΔT	average value A++		calculated			exterior dimensions	wall thickness total	usable vol.
	°C	W/m²	W/L	W/m²	W/L	% A++	Mm	mm	Liter
A++ cubic: 48 mm PU-insul.	20	2.82	0.039			100 %	600x600x1400	52	258
cylindrical with VSI	20			1.87	0.017	44%	Ø 600 x 1400	16	285
cubic with VSI	20			1.78	0.017	44%	600x600x1400	16	369

The saved electrical energy possible with such a refrigerator is significant. The consumption of 0.017 W/L amounts to only 44% of an average commercial A++ refrigerator.

Given that the usage volume of a cylindrical refrigerator with 285 liters exceeds the usage volume of a cubic A++ refrigerator with external dimensions 600 x 600 x 1400 mm by approx. 10%, there would be nothing standing in the way of the use of VSI technology with these products as well (bearing in mind the assumption – which we have still not yet verified – that the additional VSI-related costs are within the desired scale).

The potential offered by the cubic refrigerator with VSI is even greater. A considerable increase in usable volume with identical external dimensions is paired with energy savings.

Conclusion

The use of VSI can bring about considerable energy savings. It also offers the potential for additional advantages such as a greater usable volume with the same external dimensions or the same usable volume but with smaller external dimensions and increased energy savings.

All estimates to date regarding the unavoidably higher initial costs of the VSI version (compared to using conventional thermal insulation materials such as PU and mineral wool) show that the additional investment pays for itself within a payback period of 5 to 8 years thanks to the energy cost savings generated.

It should be noted that examples such as using VSI for the themoblock or boiler will be implemented for large series products in the near future but for more complex applications such as VSI for refrigerators, considerable development work still remains to be done.

References

[1] Dieter Rath, *Wärmetransport in evakuierten Dämmsystemen*, Diss, Univ. Dortmund 1989

[2] VDI-Wärmeatlas 10. Auflage 2006, *Superisolationen*, KF2, Springer Verlag Berlin Heidelberg 2006

[3] www.topten.eu

Early replacement of circulator pumps - lessons from 400,000 PumpsChecks motivating one in two German home owners

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Abstract

An online dialogue PumpsCheck was operated and promoted over the period 2006 - 2012 in Germany and used 430,000 times, motivating over 200,000 early replacements of inefficient circulator heating pumps with high-efficiency pumps in residential buildings. A government grant program operating over 2009 - 2010 was stopped because of overwhelming demand since it promoted a highly profitable investment.

A 24.4 year average life span of circulator pumps was derived from 28.234 PumpsCheck uses from 2010 to 2012, much higher than the often assumed 10 years. Thus, more than half of the standard pumps installed in 2012 might still run in 2037, if earlier replacement is not promoted successfully. About 1.200 € will be the average net loss of German home owners who miss early replacement, since standard pumps consume 2.1 kWh/sqm,a vs.0.4 for equivalent high efficiency pumps.

Also analyzed are questionnaire responses by a subset of users who gave their email addresses.

While online dialogue advice on low-cost products like high-efficiency pumps is shown to (a) motivate cost-effectively, (b) help time-pressured installers sell a low-margin product, and (c) be replicable cost-effectively in larger EU member state – it is insufficient to encourage full replacement within 10 years. However, cross-selling with boilers shows promise in also furthering early pump replacements.

General overview

10% of electricity consumption of residential and commercial buildings in EU member states is caused by 100 million circulator pumps, which pump hot water from the boiler to the radiator and back again. Annual time of operation is – depending on regional climate – roughly 6.000 hours. At an average power of about 100 Watt, their electricity consumption amounts to roughly 60 Terawatthours per year.

Early in the last decade much improved pumps ("high efficiency circulators") entered the market, consuming just 10-20 per cent of the electricity of comparable old "standard circulators".

Replacing all standard circulators with highly efficient ones in the EU would, thus, cut electricity consumption and operating costs considerably, as well as CO2-emissions.

To capture the potential of this new technology, circulator pumps were included in the ErP directive[1], which mandated installation of the new highly efficient circulators, starting 2013. This affected only the two smaller market segments: Installations in new buildings and replacement of broken circulators. The largest segment, however, the installed stock of inefficient pumps was left untouched.

The ErP directive does not impose an unacceptable burden on building owners, since the cost of installing a high efficiency circulator exceeds that of a standard circulator only by 50 - 125 Euro[2]. That is very little, compared to the 1.200 Euro net present value of future electricity costs saved over the 15 years average remaining life-time of a 10 year old standard pump (assuming 400 kWh/a saved at 0,30 €/kWh average future electricity price in Germany). However, no rapid reduction of electricity con-

[1] ErP Directive 2009/125/EC (Energy related Products; formerly EuP Energy using Products)

[2] Grundfos UPS vs. Alpha 2, Wilo Star RS vs. Stratos Pico; total cost of high efficiency circulators, including 200 € for installation, are 350 - 525 € (source: www.pumpendiscounter.de, June 2013)

sumption can be expected, since the obsolescence rates of circulators are very low, their average life expectancy being about 25 years. So even in 2037, 25 years from now, only half of all standard circulators installed in 2012 will be replaced by highly efficient ones based on current trends.

Speeding up this process of replacement would thus benefit the environment and the citizens of Europe, and it would reduce Europe's dependence on fossil fuel imports considerably.

The early replacement of a standard by a high efficiency circulator adds considerably to the wealth of a home owner, since the net present value of such an investment outweighs the investment costs for a pump of average age by 300 - 400 percent.

There are two standard policies to encourage early replacement: (1) National legislation mandating early replacement, (2) incentives like national subsidy schemes or motivation campaigns among home owners for early replacement of the electricity "guzzler" in their boiler rooms. Only the latter have been used during the German campaigns "Klima sucht Schutz" (Climate seeks Protection, 2004 - ongoing) and "Sparpumpe" (Saving Pump, 2009 - ongoing), run by co2online[3] and backed by the German Ministry for the Environment. Only since 2013 the ErP directive forces the homeowner to buy a highly efficient circulator, while early replacement, even if highly profitable, is not mandated.

Why are sales of high efficiency pumps so slow?

Before considering policies to speed up the early replacement of standard circulators by highly efficient ones, we need to analyse why a revolutionary device, which uses only 10-20 percent of the electricity its predecessor needs, is selling so slowly.

One reason is inherent in the multi-level structure of the boiler market: Manufacturers sell to wholesalers, wholesalers to installers, and installers to homeowners. Thus, not the manufacturer but the installer is or should be communicating the benefits of a highly efficient circulator to the homeowner. But selling a new circulator is of little interest to the installer because of its relatively low price[4] and therefore small margin. In the end the good news never reaches the homeowner, often not even once his/her circulator breaks down.

So two structural problems are at the core:

- The multi-level structure of the market and the consequently low incentive for the installer to actively promote an early replacement.
- The gap between the huge financial benefit of an early replacement for the homeowner and the low financial benefit for the installer from an order to replace the old circulator by a new one.

Since these structural problems can hardly be dissolved, co2online is looking for other ways to increase early replacement rates, as shown below.

The motivation campaign for early replacement of circulators

In 2006, co2online launched its first version of the interactive PumpsCheck[5], one of 2 dozen online energy savings advice tools, backed by annual grants from the German Ministry for Environment.

The PumpsCheck compares the electricity consumption, operating cost, and CO2-emissions related to the existing circulator with the full cost (including depreciation!), consumption, and emissions of a high

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[3] co2online gemeinnützige Beratungsgesellschaft is a non-profit limited liability consulting company campaigning to reduce emissions of carbon dioxide (CO_2) by means of energy saving through dialogue. co2online motivates private households, trade and commerce to become actively involved in climate protection and to save money at the same time. co2online implements several campaigns for private households and communities, co-funded by the German Ministry for the Environment. (www.co2online.de)

[4] Around 350 - 525 Euro, including installation and VAT.

[5] www.klima-sucht-schutz.de/energiesparen/energiespar-ratgeber/pumpencheck.html

efficiency circulator. The comparison is based on estimating the electricity consumption of both, by supposing 5,500 operating hours per year, and by reducing the power of a new circulator to that actually required by the building. Thus, the PumpsCheck serves a twofold purpose: As a sizing tool, it calculates the capacity (kW) needed for the new circulator, and as a decision support tool, it estimates the economic benefit of an early replacement. So every homeowner can find his/her old circulator in the circulator database, enabling him/her to correctly calculate the net present value of his/her investment and/or the payback period for a correctly sized replacement.

co2online offers this PumpsCheck as a free online service for anonymous use. Nevertheless, about 1 in 20 users also enter their email address to download a PDF-file with the complete calculation that led to the final recommendation ("a data-sheet") or for further questions. Those PumpsCheck users receive a questionnaire by email about one year later. The answers from those questionnaires allow the following conclusions:

Giving cost-free circulator advice to home owners via the internet is effective in that 44% of respondents to the 2010 questionnaire said that they had followed the replacement advice given by the PumpsCheck and had replaced their circulator within one year after the advisor session. A further 37% of users claimed that they had decided to do so within the next twelve months. Only 3% of the users had pumps that were not working[6]. In addition, 90% of those who had replaced the circulators confirmed that they followed the recommendation on the size of the new pump given by the PumpsCheck[7].

At about 900 uses per week[8], the PumpsCheck is not the only co2online tool that recommends the early replacement of old and inefficient circulators. Three more tools[9] address related household information issues, and also recommend early replacement of appliances, if appropriate:

- ThermostatCheck (ThermostatCheck), for advice on early replacement of old thermostat valves
- HeatingCheck (HeizCheck), for advice on hydraulic balancing of the heat distribution system
- RefurbishmentCheck (ModernisierungsCheck), for advice to people considering a partial or full thermal modernization of their building (heating system and building envelope).

In total, the impact of all those advice tools together adds up to the replacement of about 2,500 circulators per week, or more than 100,000 per year. Thus the number of pumps replaced due to co2online's pumps campaign roughly corresponds to the number of all early circulator replacements in Germany, estimated at roughly 100,000-150,000 per year, as corroborated by industry sources[10].

Judging the German pumps campaign by the ratio of "pump replacements after completed advisor sessions" over "total completed advisor sessions", the campaign is astoundingly successful. Nevertheless, a look at the "total stock of old and inefficient pumps" versus the "pumps replaced early every year", shows its shortcomings. Industry experts[11] estimate the total stock of old and inefficient circulators still operating in the cellars of German residential buildings at 22 million. Over the next 10 years, about 10 million will break down and be replaced anyway. However, as high efficiency pumps recover their cost (parts plus labour) in less than 5 years, even 5 of those 10 million should still be replaced early. If replacement of these 17 million were to be spread evenly over 10 years, 1.7 million per year would be the target against which 100,000 - 150,000 actual early replacements are close to insignificant. Thus, even a good campaign hardly speeds up the replacement process as a whole.

[6] ISoMe Institut für soziologische Meinungsforschung Evaluation interaktiver Energiespar-Ratgeber im Rahmen der Kampagne „Sparpumpe"; PumpenCheck und www.sparpumpe.de, Ergebnisbericht Juli 2010, Download: www.co2online.de/fileadmin/CO2online/PDF_Evaluationen/PumpenCheck-Sparpumpe_Evaluation-2010_Bericht.pdf

[7] As in footnote 6, above, page 29

[8] www.co2online.de/statistik-und-research/ratgebernutzung/index.html?no_cache=1, click on the first „Details" for usage of each adviser per week

[9] www.klima-sucht-schutz.de/energiesparen/energiespar-ratgeber.html

[10] Personal communication from marketing managers of Grundfos, KSB, and WILO in Germany

[11] Personal Communication to Johannes D. Hengstenberg, 2012

Any increase of early replacements beyond 100,000 is hard to accomplish, because homeowners show limited active interest in saving electricity and costs. And, any "managed" increase of public interest in the topic by spending more money on internet advertising is getting increasingly expensive due to increased content competing for internet users' attention. Therefore, a pumps-only campaign is – beyond a certain limit – not scalable.

Legislative measures to push the early replacement

Over 1,000 completed PumpsCheck sessions every week generate a vast collection of data on co2online's servers. This data shows:

- The payback period from early replacement is on average 4 years
- The average rate of return on investment (ROI) is as high as 13%
- The average economic benefit for a home owner from replacing a standard circulator with a high efficiency circulator early is about 1,200 Euro – using the net present value of the investment (discounted future electricity cost saved minus cost of replacement).

This shows that the average early replacement of an inefficient circulator is beneficial for the average homeowner, because it increases his/her wealth in the vast majority of cases. Thus, a law mandating early replacements of circulators is viewed by the author as being:

- compatible with the Basic Law of the Federal Republic of Germany (Grundgesetz Art. 14[12]), which strictly forbids any infringements on private property by public authorities,

and it would be

- more cost-effective than a replacement campaign which must "buy" the attention of German home-owners for the benefits of early replacement through increasingly expensive web-based advertising campaigns.

In particular, a legal mandate would be best if limited to coincide with other refurbishment measures like replacement of the boiler or improvements in the building envelope. Given the current energetic modernisation rates of residential buildings in Germany of only 1 - 3% per year, the number of related early pump replacements could be handled by installers,

In the first case (boiler replacement), a new circulator would leverage the efficiency of the new boiler if it were a condensing boiler whose efficiency crucially depends on low return temperatures, which only a modulating high efficiency circulator can provide. In that case, the profitability of the boiler replacement would be increased by the additional savings of fuel caused by higher boiler efficiency.

In the latter case (thermal insulation), the original heating-demand estimate, on which the capacity of the old circulator was based, is no longer valid due to the reduced heat demand in the building after refurbishment.

Despite the vast empirical evidence supporting mandatory early replacement (e.g. in the upcoming German Energy Ordinance (EnEV) of 2014), the effort was stopped by German politics. Supposedly it is not compatible with the general "philosophy" of the ruling conservative (CDU/CSU) and liberal (FDP) parties, which tend to be rule-averse and hope for citizens' self-interest and market powers to realise savings potentials.

Grants for early replacement of circulators

From April 2009 to August 2010, co2online had succeeded in convincing policy makers to set up a federal subsidy scheme: Grants of 25% to the total cost (labour & parts) of replacing a circulator, which roughly amounts to 400 € for small single family buildings and correspondingly more for multi-family buildings.

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[12] dejure.org/gesetze/GG/14.html

The success of the scheme was tremendous. Up to 2,000 grant applications per day arrived at the KfW Förderbank, the German bank handling many state subsidies. That work load the bank could not cope with in the long run. After 161,000 grants[13] had been approved, the KfW added hydraulic balancing of the heating system ("Hydraulischer Abgleich") as an additional grant requirement[14]. As a result, grant applications shrank to less than 10% of the initial volume[15], since not enough installers in Germany could provide this additional service at the time. But even if the KfW had been able to cope with 2,000 applications per day, the subsidy scheme suffered from a major deficiency: It subsidized a measure that was extremely profitable for the homeowner even without that subsidy. So, from a constitutional point of view, the subsidy scheme wasn't a sustainable solution to tackle the high stock of outdated and inefficient circulators.

General outlook: What to do with outdated circulators?

As we have seen, the ErP directive does not tackle the large stock of old, still functioning circulators, since it only addresses replacement of broken ones (and new construction). Other measures, like online awareness campaigns, are successful but of limited reach because they are not scalable. The same holds true for government subsidies, which are inconsistent with the public finance principle that no activities should be subsidized which are highly profitable, per se.

For the moment, only one perspective might prove viable: Evaluations of the PumpsCheck impact show high cross-selling potentials of circulators, which means that one in six circulator replacements coincide with one boiler replacement. From a sales perspective, installers contracted to replace a pump on average end up with 2-3 times more turnover generated from the sale of boilers than from the sale of pumps.

So pumps may serve as lead generators for boiler sales – which implies that part of the marketing costs for pumps should picked up by boiler manufacturers – to their and the pumps manufacturer's benefit. Currently, co2online explores those cross-selling potentials with manufacturers of both, hoping to speed up early replacement and to shorten the time span needed until all circulators in Europe are highly efficient.

[13] www.kfw.de/Download-Center/Konzernthemen/Research/PDF-Dokumente-alle-Evaluationen/Monitoring-Energieeffizient-Sanieren-2010-Bauen-2006-bis-2010.pdf, page 30

[14] www.sparpumpe.de/foerderung-sichern/kfw-streicht-sonderfoerderung/index.html

[15] www.energiesparclub.de/?id=4124

Office Luminaires: Voluntary Labels Can Pave the Way to the Next Level In Energy Saving

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Abstract

Energy savings in lighting can be taken to a new level by introducing mandatory EU minimum requirements and an energy label considering the luminaire efficiency factor (LEF).

We look back on EU policies introduced during the last 15 years regarding luminous efficacy of light sources and ballast efficiency. The third parameter however, the light output ratio that defines the efficiency of a luminaire, has not yet been addressed by labelling or ecodesign measures. High energy saving potential is left to tap here.

Four voluntary labels and initiatives (*Minergie, Der Blaue Engel, Energy Star, Topten.eu*) guide to the current best available technology. They can be an inspiration to EU labelling and ecodesign measures. This paper portrays the four labels and discusses their different approach to set LEF requirements. Most ambitious requirements are specified for ceiling-mounted luminaires and pendant luminaires with minimum LEF of 75 lm/W at 3000 lumens (requirements ease with lower luminous flux, increase with higher luminous flux). It could be useful to base future LEF requirements on the formula described in the new regulations (EU) No 874/2012 and (EU) No 1194/2012. This would mean capped LEF requirements for luminaires above 1300 lumens.

Introduction

Lighting offers great potential for energy savings. EU labelling and ecodesign policies have pushed to increase the luminous efficacy of light sources since 1999 when the energy label for household lamps was introduced. Starting in 2009, poorly performing lamps have been banned from the market in several stages. By 2016, the last stage defined in the current ecodesign regulations, only improved halogens[1] and well performing fluorescent lamps, LED lamps and high intensity discharge lamps will meet the minimum requirements. Also ballast losses have been limited in several stages since 2002. [1] - [6]

The efficiency of a luminaire is determined by three parameters: the luminous efficacy of the light source (lm/W), the efficiency of the ballast (%) and the light output ratio “LOR” of the luminaire (%). The luminaire efficiency factor “LEF” (lm/W) indicates the luminous flux emitted from the luminaire per watt electrical power consumed; it equates to the product of the three mentioned parameters as shown in Figure 1.

[1] Infrared coated or xenon filled low voltage halogens and mains voltage halogens with transformer; exceptions: lamp cap R7s and G9

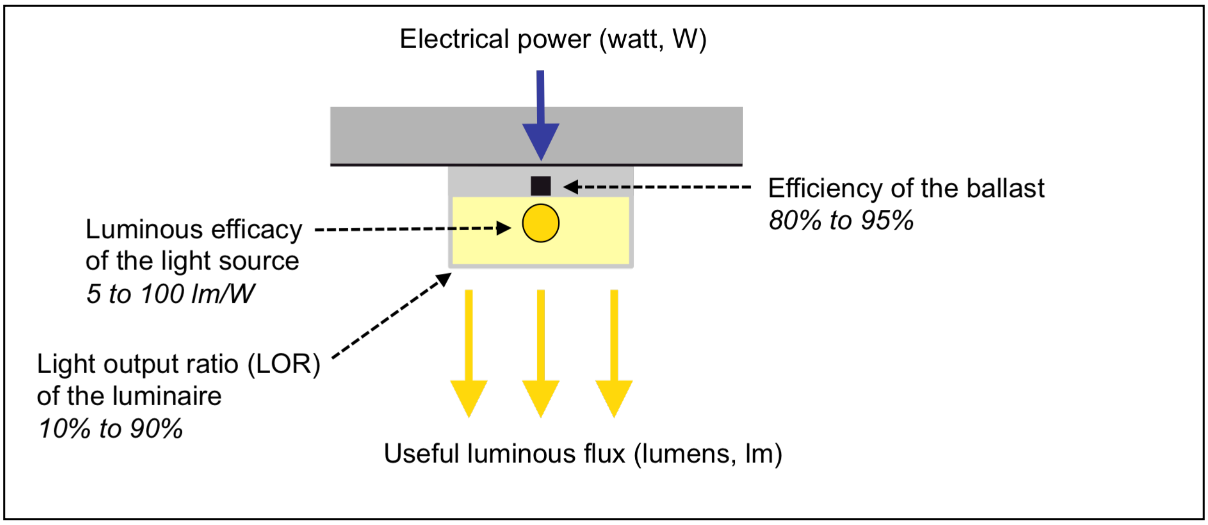


Figure 1: Parameters of the luminaire efficiency factor (LEF)

Aim of this paper

Both luminous efficacy of light sources and ballast efficiency have been in the scope of EU policies for over a decade. The third parameter however, the light output ratio that defines the efficiency of a luminaire, has not yet been addressed by labelling or ecodesign measures. High energy saving potential is left to tap here. LOR ranges from very small, where most of the lamp luminous flux is lost, to high, where the luminaire emits nearly all of the lamp's light. This leads to a range in LEF between 5 lm/W to over 90 lm/W.

Against that background the authors of this paper advocate the introduction of a mandatory EU energy label and minimum requirements for office luminaires.

In public perception office lighting is less prominent than household lighting even though it accounts for twice the energy consumption. Office lighting consumed an estimated 164 TWh in 2007; household lighting consumed 84 TWh in 2007 and 80 TWh in 2009 [11].

Energy labelling and ecodesign measures could be more easily introduced for office luminaires for several reasons:

- Product information for most office luminaires on the European market is already available in lighting simulation software such as Dialux and Relux. The standardized data format is Eulumdat with the file extension *.ldt (the American IES format can be transformed into Eulumdat).
- Office luminaires are generally installed by professionals. A mandatory energy label would be a strong incentive for electricians, planners, private and public procurement agents, and awarding authorities to consider the LEF.
- The energy label could provide information on the annual energy consumption (kWh/year) for typical use. This would directly support the goals of the recast Energy Performance of Buildings Directive 2010/31/EU which asks to consider built-in lighting installation for the calculation of energy performance of buildings. It would give EU countries a tool to implement energy performance standards. On the other hand the energy label could operate independently. Standards such as EN 12464-1 specify the minimum illuminance (lux) per square meter required for work places. These specifications can be met with manifold luminaire types. The energy label would help to distinguish whether the chosen luminaire is performing well or poorly regarding LEF.
- Office luminaires tend to require specific light sources; this makes determining the test lamps easier. Lamps with E27 cap are typically used for household luminaires and come in many variations; things become more complex.

Voluntary labels promoting office luminaires with high LEF are established in some countries. They can be an inspiration to EU labelling and ecodesign measures. This paper gives an overview of four voluntary labels and their LEF requirements.

Note that an EU energy label will be provided for household luminaires from March 2014 on [2]. This label is not important for the discussion in this paper, because it does not inform about the energy efficiency of the luminaire itself; it only informs about the type of lamps to be used in the luminaire. LEF or LOR are not addressed.

Voluntary labels promoting luminaires with high LEF – 4 portraits

"*Minergie*" from Switzerland, "*Der Blaue Engel*" from Germany and "*Energy Star*" from the USA belong to the classical type of voluntary label: manufacturers purchase the license to label their eligible products. "*Topten.eu*" is an initiative (funded by Intelligent Energy Europe (IEE) and coordinated by ADEME) aiming to stimulate demand for the most energy efficient products in national markets and to support EU labelling and ecodesign policies. For this purpose the best available technology is presented online with no cost to manufacturers.

Facts and figures for "*Minergie*" and "*Der Blaue Engel*" are summarized in Table 1, for "*Energy Star*" and *"Topten.eu"* in Table 2.

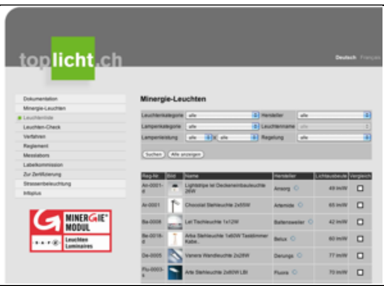
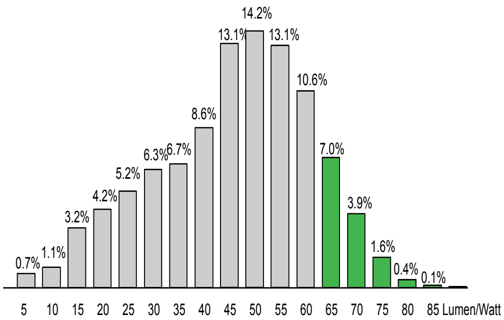
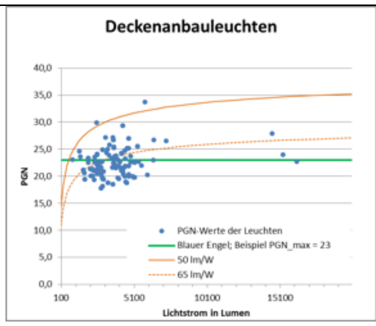
Minergie in Switzerland	Der Blaue Engel in Germany
Since 2007, today 791 luminaires of 27 brands	Conditionally adopted by Eco-Label Jury in December 2012, planned to start in mid 2013
26% LED products	-
Non-directional and directional	Non-directional and directional
– ceiling-mounted – recessed – suspended – floor-standing – desk – wall-mounted – spots – downlights	– ceiling-mounted – recessed – suspended – floor-standing – desk – wall-mounted – spots – downlights
http://www.toplicht.ch/index.php?page=minergieleuchten	http://www.blauer-engel.de/
	
Rationale behind LEF requirement: LEF criteria are set in order to represent the top 15% products of the market (analysis of data set from Relux for 16'000 luminaires with class A and B lamps and electronic ballasts).	*Rationale behind LEF requirement:* LEF criteria are based on the equation for lamps in the EU regulation 98/11/EC. They are set in order to be about 30-50% stricter than Minergie depending on the type of luminaire.
 LEF of 16'000 luminaires on the market in 2006 (all lamps class A + B)	 Minergie data for ceiling-mounted luminaires. x-axis: luminaire luminous flux (lm). y-axis: PGN as index for energy efficiency; lower PGN value means better performing. Green line: PGN requirement. $PGN(P, \Phi L) = P / (0.01029 * (0.88 * \sqrt{\Phi L}) + 0.049 * \Phi L))$ with ΦL = luminaire luminous flux (lm) and P = power (W).
Other criteria considered [7]: – Standby power (limits: 0 watt; exceptions: dimmable ballast: 1 watt, presence detection / daylight sensor: 0.5 watt) – For LED: CRI $R_a \geq 80$; life time ≥ 20'000 hours (with Lamp Lumen Maintenance Factor LLMF ≥ 70%); power factor ≥ 0.5 or 0.9 depending on power – Ballast (only electronic) – Unified Glare Rating	*Other criteria considered [8], [12]:* – Standby power (limits: 0.1 watt; exceptions: dimmable ballast or external power supply unit: 0.5 watt) – For LED: life time ≥ 20'000 hours (with LLMF ≥ 80% and Lamp Survival Factor LSF ≥ 90%); switching cycles ≥ 100'000 – Modularity of ballasts – Modularity of LED-downlights – Ultraviolet and electromagnetic radiation – Mercury in fluorescent lamps (limits: T5: 1.4 mg; T8: 2.0 mg; CFL: 1.4 mg) – Provision of spare parts (at least for 10 years) – Comprehensive information for users and procurement agents

Table 1: Portraits of Minergie (Switzerland) and Der Blaue Engel (Germany)

Energy Star in the USA	**Topten.eu for Europe**
Since 2008, today 7350 luminaires of 159 brands	Since 2012, today 71 luminaire lines of 18 brands
21% LED products	28% LED products
Only directional luminaires[2]	Non-directional and directional
– accent lights (includes line-voltage directional track lights) – downlights: recessed, pendant, surface mount (includes SSL downlight retrofits, excludes troffers or linear forms) – under cabinet shelf-mounted task lighting – portable desk task lights	– ceiling-mounted – recessed – suspended – floor-standing – desk – wall-mounted – spots – downlights
http://www.energystar.gov/lightfixtures	http://www.topten.eu/english/criteria/office_lighting_crit.html&fromid=
	
Rationale behind LEF requirement: Generally, a market share of Energy Star qualified products in a particular category of 50% or higher will prompt consideration for a specification revision.	*Rationale behind LEF requirement:* LEF criteria are based on *Der Blaue Engel*. As products improve, Topten criteria become stricter; lists stay limited to the 10 or so best luminaire lines in each class. For this reason LEF criteria for ceiling-mounted and pendant luminaires are stricter than *Der Blaue Engel*.
(no figure available)	(no figure available)
Other criteria considered [9]: – Standby power (limits: 0 watt; exceptions: presence detection, daylight sensor etc.: 1 watt) – For LED: CRI $R_a \geq 80$; lumen maintenance ≥ 94% at 6'000 hours; color angular uniformity; color maintenance; power factor ≥ 0.5 or 0.9 depending on power – For FL and HID lamps: CRI $R_a \geq 80$; lumen maintenance ≥ 80% at minimum 4'000 hours; power factor ≥ 0.9 – All luminaires shall be shipped with a lamp for each lampholder (few exceptions) – Warranty (minimum 3 years) – And many more ... (ballast performance, thermal performance, product labeling & packaging etc.)	*Other criteria considered [10]:* – Same as *Minergie*; only exception standby power limit for dimmable ballast: 0.5 watt (same as *Der Blaue Engel*)

Table 2: Portraits of Energy Star (USA) and Topten.eu (Europe)

[2] Non-directional residential luminaires can earn the *Energy Star* label, but criteria are set for the light source, not the luminaire.

Comparison of LEF requirements

Topten.eu, *Der Blaue Engel* and *Energy Star* classify luminaires according to mounting types. *Minergie* classifies according to light source technology and directional characteristic[3]. For sake of comparison office luminaires that are typically directional (such as ceiling-mounted, downlight, accent and desk luminaires) are grouped and typically non-directional luminaires (such as pendant, wall and floor-standing) likewise. Figure 2 shows the minimum LEF requirements for directional luminaires as well as the future EU minimum energy efficiency requirements for directional lamps that will be applied from 2016 on ((EU) No 1194/2012 [6]). Figure 3 shows for non-directional luminaires and lamps.

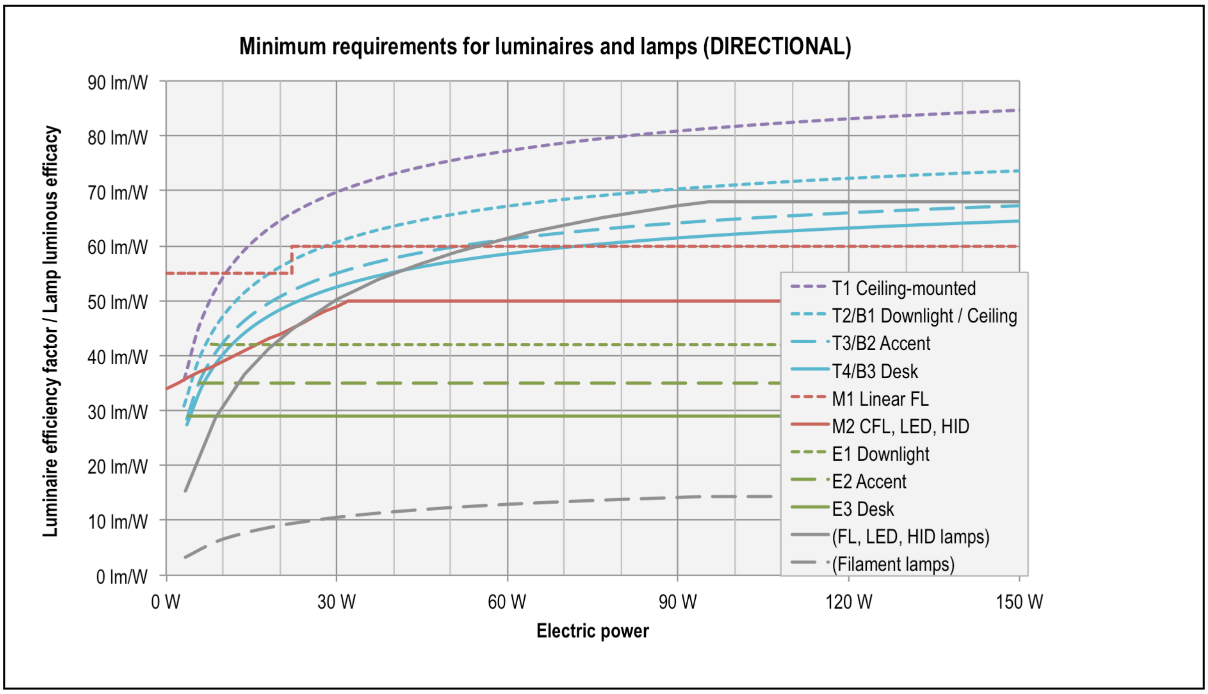


Figure 2: Minimum LEF requirements for directional luminaires. T1-T4 = *Topten.eu*, B1-B3 = *Der Blaue Engel*, M1-M2 = *Minergie*, E1-E3 = *Energy Star*, (... lamps) = EU ecodesign 2016.

Luminaires with lower power, or lower luminous flux, have a lower LEF mainly because the ballast contributes proportionally more to the power consumption. All LEF requirements with the exception of *Energy Star* are less strict for luminaires with lower power / luminous flux. This relation is described either by the equation given in EU regulation 98/11/EC for lamps [1] (*Der Blaue Engel, Topten.eu*) or by a simpler approach like a linear function or simply a minimum LEF value (*Minergie*). Note that none of the 4 labels uses the approach given in EU regulation 1194/2012 for lamps [6]. Those newest minimum requirements are capped for lamps over 1300 lumens.

Der Blaue Engel LEF requirements become increasingly stricter with higher luminous flux. All other LEF requirements are capped (the highest cap being 70 lm/W for non-directional linear FL luminaires set by *Minergie*).

Topten.eu sets the strictest LEF requirements for ceiling-mounted and pendant luminaires; otherwise it is in line with the German Eco-Label *Der Blaue Engel.* The latter is stricter than *Minergie,* which again is stricter than *Energy Star*.

[3] A revision of the *Minergie* criteria is foreseen for January 2014 switching to a classification according to mounting types too.

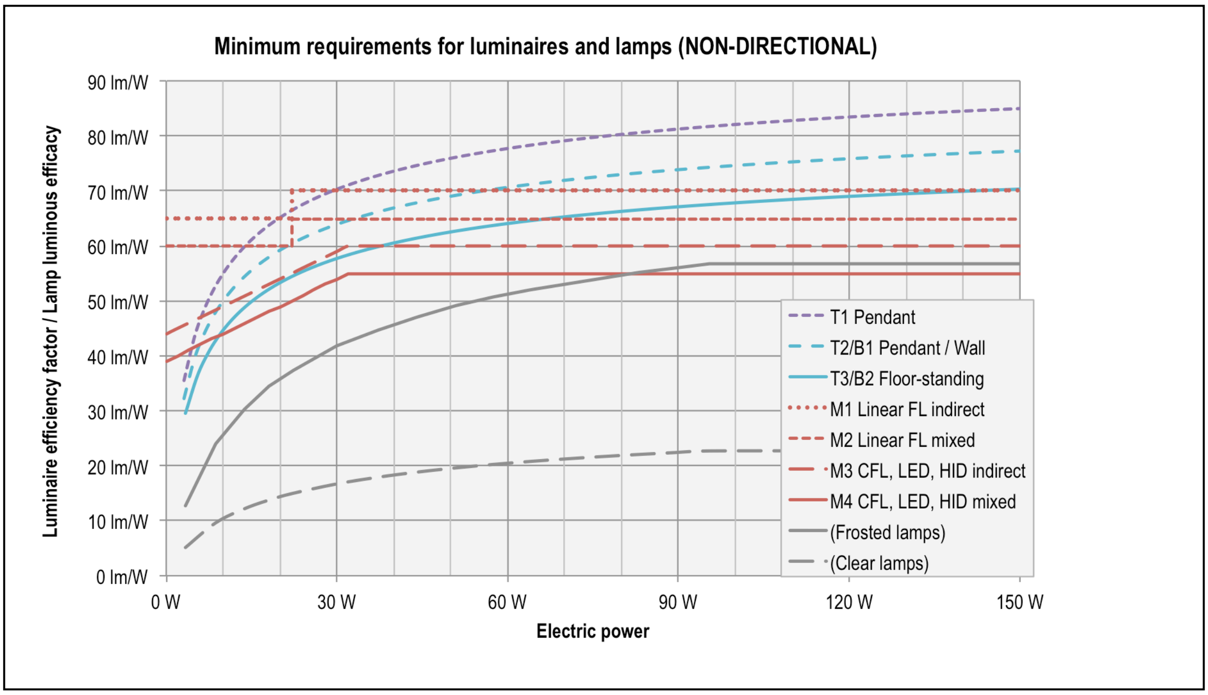


Figure 3: Minimum LEF requirements for non-directional luminaires. T1-T3 = *Topten.eu*, B1-B2 = *Der Blaue Engel*, M1-M4 = *Minergie*, (... lamps) = EU ecodesign 2016.

Discussion

The four voluntary labels promoting luminaires with high LEF can serve as guideline, should the European Commission work out measures for office luminaires. They indicate the best available technology (and in the case of *Energy Star* the average available technology). A future EU energy label could base its top classes on the labels' LEF requirements, while considering that further efficiency improvements are expected for LED luminaires.

There are different approaches how to set LEF requirements, as explained in the above chapter. At this point the authors of this paper would recommend using the same formula as the new regulations (EU) No 874/2012 and (EU) No 1194/2012 (with capped LEF requirements for luminaires above 1300 lumens). *Minergie* intends to adapt that approach at a revision planned for January 2014.

Associated with the *Minergie* revision current luminaire data from the Relux database has been analyzed. There is no publication available (yet); still we would like to mention some of the results. The database contains ca. 600'000 data sets in total, though 71% are duplicates or incomplete. Data sets for 175'680 luminaires were found to be useful. 62% are equipped with linear fluorescent lamps (LFL), 20% compact fluorescent lamps (CFL), 12% high-intensity discharge lamps, 4% filament lamps and 2%, or 3760 luminaires, with LED. The median LEF of LED luminaires is 55 lm/W, of CFL luminaires 23 lm/W and of LFL luminaires 33 lm/W. This makes LED luminaires to date typically twice or so as energy efficient compared to luminaires with fluorescent lamps. The top 10% of LED luminaires have a LEF of 77 lm/W, of CFL luminaires 46 lm/W and of LFL luminaires 66 lm/W.

The four voluntary labels also indicate which criteria beyond luminaire efficiency might be worth considering. We highlight only two criteria here; please refer to the original specifications [7] - [10] for the complete criteria sets. All four labels limit standby to 0 watt (with exceptions for presence detection / daylight sensor and dimmable ballasts). They also set requirements for LED products that in some cases go beyond regulation (EU) No 1194/2012 (e.g. lumen maintenance factor 70-80% at 20'000 hours, lamp survival factor 90% at 20'000 hours, 100'000 switching cycles).

References

EU labelling and ecodesign regulations

[1] Commission Directive 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps (to be replaced by regulation 874/2012)

[2] Commission Delegated Regulation (EU) No 874/2012 of 12 July 2012 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of electrical lamps and luminaires

[3] Directive 2000/55/EC of the European Parliament and of the Council of 18 September 2000 on energy efficiency requirements for ballasts for fluorescent lighting (replaced by regulation 245/2009)

[4] Commission Regulation (EC) No 244/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps

[5] Commission Regulation (EC) No 245/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council

[6] Commission Regulation (EU) No 1194/2012 of 12 December 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment

Voluntary labels: Specifications

[7] Reglement und Nachweisverfahren zur Vergabe des MINERGIE®-Labels für Leuchten. Durch Labelkommission genehmigte Version vom 11.9.09. Ausgearbeitet durch Schweizerische Agentur für Energieeffizienz S.A.F.E.

[8] Vergabegrundlage für Umweltzeichen, Leuchten für die Anwendung in Büros und verwandten Einsatzbereichen, Ausgabe 2012 (DRAFT)

[9] ENERGY STAR® Program Requirements Product Specification for Luminaires (Light Fixtures), Eligibility Criteria Version 1.2

[10] Topten.eu Selection Criteria for Office luminaires: http://www.topten.eu/english/criteria/office_lighting_crit.html&fromid=

Other References

[11] Bertoldi P., Hirl B. and Labanca N. *Energy Efficiency Status Report 2012*. European Commission, Joint Research Centre, Institute for Energy and Transport.

[12] Schleicher T., Liu R. *Top 100: PROSA Leuchten für die Anwendung in Büros und verwandten Einsatzbereichen – Entwicklung der Vergabekriterien für ein klimaschutzbezogenes Umweltzeichen*. Studie im Rahmen des Projektes "Top 100 – Umweltzeichen für klimarelevante Produkte", Öko-Institut e.V. 2013 , http://www.oeko.de/oekodoc/1775/2013-464-de.pdf

An investigation of the power consumption and quality of supply of LED lamps

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University of Stellenbosch, Department of Electrical and Electronic Engineering

Abstract

Residential and Commercial Energy Efficiency projects conducted as part of Demand Side Management (DSM) interventions involve the exchange of inefficient lighting technologies with newer, more efficient lighting technologies to reduce the overall electricity usage. In the residential sector, these interventions often target halogen lamps which are replaced by Light Emitting Diode (LED lamps) lamps. The Measurement and Verification (M&V) of the energy savings impacts of these types of projects requires that baseline and post-implementation energy consumption profiles are determined for the lighting technologies removed and installed in the intervention. The relationship between the power consumption of the lighting technologies and the supply voltage magnitude are taken into consideration. Supply current waveforms of LED lamps exhibit very high degrees of harmonic distortion. The measured results for three-phase LED lamps loads have shown that the LED lamps give rise to zero-sequence, i.e. neutral, current loading. This is a potential cause for concern, especially for underrated networks.

This paper presents the results of a laboratory investigation to determine the effects of supply voltage magnitude on the power consumption of various LED lamps utilised in energy efficiency interventions. The power consumption is measured for supply voltages ranging from 207 V to 253 V, i.e. 90 % of the nominal supply voltage (in South Africa) of 230 V to 110 % of the nominal supply voltage. Variations up to 26 % of rated power are measured. Results of an investigation of the Quality of Supply related to LED lamps is also presented. Total Harmonic Distortions (THDs) as a high as 133 % are measured for the current waveforms.

Overview

The mass deployment of Light Emitting Diode (LED) lamps forms an important part of the current Demand Side Management (DSM) strategy designed to achieve energy savings and reduce the electrical demand in peak periods when generation and network capacity constraints are experienced. LED lamps are generally introduced in the place of conventional inefficient halogen lamps in the residential and commercial sector. Incandescent and halogen lamps represent a stable resistive load with little or no negative impact on the Quality of Supply (QOS) of the associated electrical supply networks. A typical LED lamp, on the other hand, features an electronic control circuit that drives single or multiple light emitting diodes, and therefore represents an active load. The supply current is highly distorted and thus represents a source of harmonic distortion with the potential to adversely affect QOS as defined in national standard NRS048 [1].

From a Measurement & Verification (M&V) perspective, the voltage dependency of the active power consumption of LED lamps loads differs from that of halogen lamp loads. This may impact on the methodology applied in determining the savings impacts of LED lamp interventions.

This paper gives details of a laboratory investigation undertaken with the view to determine the voltage dependency of the active power consumption as well as the spectral properties of the supply current. The following results are presented:

- Modelling of the voltage dependency of the active power consumption.
- A spectral analysis of the supply current.
- Neutral current loading for three-phase loads.

Overview of the measurement arrangement and LED samples

Figure 1 shows the measurement arrangement. An analog to digital converter is used to capture voltage and current waveforms for post processing.

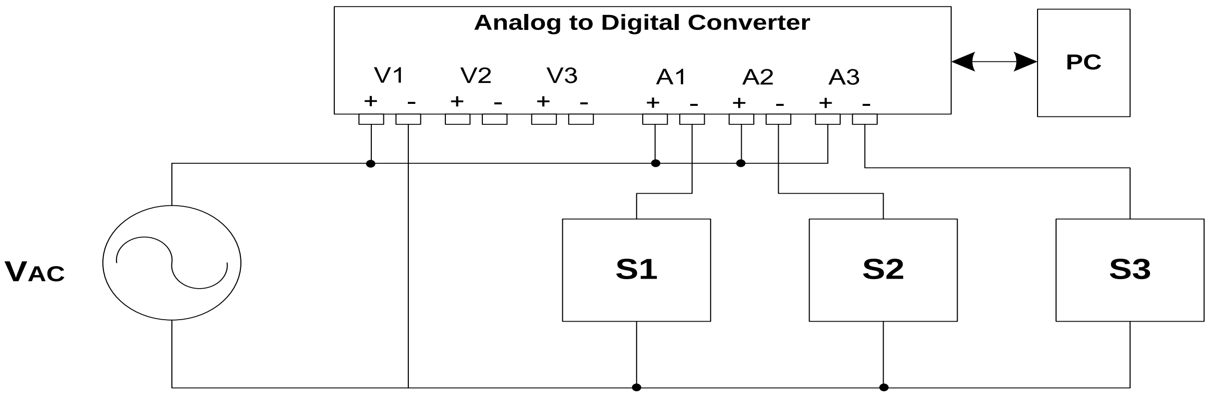

Figure 1: Diagram of the measurement arrangement.

A number of tests were conducted on commercial LED lamps using the generic test arrangement shown in Figure 1. In order to determine whether the test results are consistent for LED lamps of the same rating from the same model, three samples of each rating per model were tested. These samples are denoted S1, S2 and S3 in Figure 1. Table I summarizes the subsection of the test results that are presented in this paper.

Table I: Summary of the LED lamps considered in this report.

Model	Power Rating [W]
A	4
B	3
C	3

Table II summarizes relevant specifications of the measuring equipment.

Table II: Specifications of the measuring equipment.

Equipment	Max. Voltage	Max. Current	Sampling Rate [kS/s]
NI CompactDAQ USB Data Acquisition Systems	-	-	-
300 Vrms Analog Input Power Measurement NI 9225	300 V_{RMS}	-	50
4-Channel Current Input C Series Module NI 9227	-	5A_{RMS}	50

The data capturing and processing was performed with LabVIEW System Design Software. Table III summarizes the applicable power calculation formulas performed in LabVIEW System Design Software.

Table III: Post processing power calculation formulas.

Calculation	Formula
Average real power (P_{AVG}) [W]	$\frac{1}{T}\int_0^T v(t)\cdot i(t)dt$
Reactive power (Q) [Var]	$\sqrt{(V_{RMS} \times I_{RMS})^2 - P_{AVG}}$
Apparent power (S) [VA]	$V_{RMS} \times I_{RMS}$
Power factor	$\frac{P_{AVG}}{V_{RMS} \times I_{RMS}}$

Voltage dependency characterisation and spectral analysis

The supply voltage V_{AC} was obtained from a generator and the supply voltage magnitude is controlled by a variac. The harmonic properties of the supply current should ideally be determined for a sinusoidal supply voltage source with zero internal impedance. For practical reasons, this was not possible and a supply voltage waveform, which exhibits a small degree of harmonic distortion, was used. In practice, a small amount of distortion is typical for low voltage (LV) supply networks [1]. As a result of the small amount of voltage distortion, it is important to qualify the results by giving information for the spectral properties of both the supply voltage and the supply current waveforms. The harmonic content of the supply voltage is shown in Figure 2.

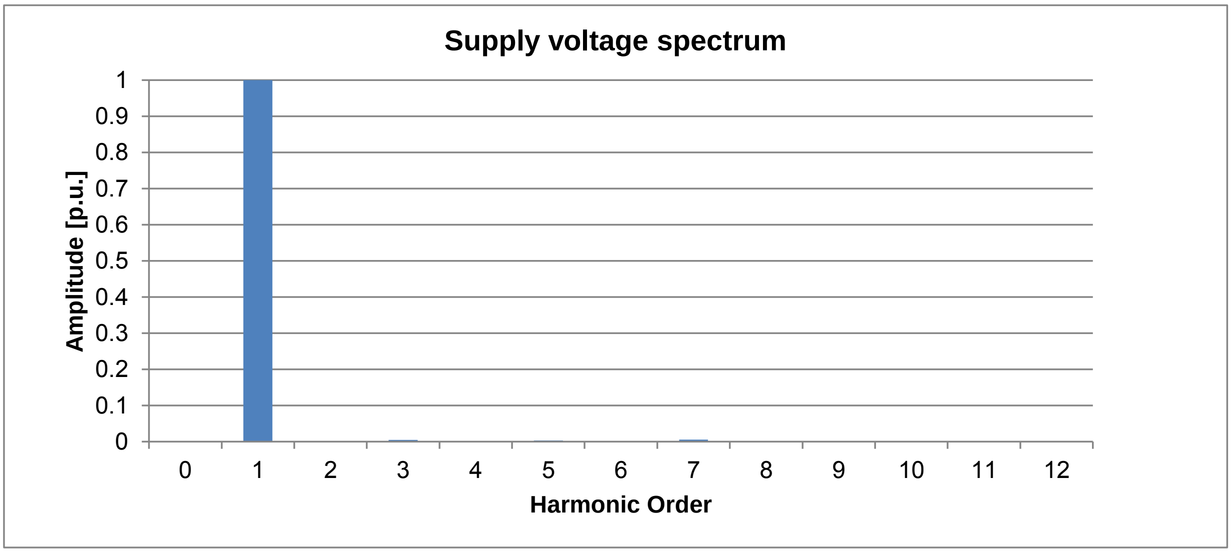

Figure 2: Harmonic content of the supply voltage

Measurement procedure

The measurement procedure can be summarized as follows:

The LED lamps that are being measured are supplied with a supply voltage of 230 V and the lamps are allowed to stabilize for approximately 5 minutes. The voltage is reduced to 207 V (10 % under the nominal supply voltage of 230 V [1]) before gradually being increased in 2 % increments to 253 V (10 % above the nominal supply voltage). The voltage and current waveforms are sampled at 50kS/s and stored for post processing. LabVIEW System Design Software is used to perform the power calculations shown in Table III and to extract the desired spectral information from the recorded voltage and current waveforms.

Measurement results for voltage dependency

Figure 3 to Figure 5 show the supply current and active power as a function of the supply voltage for the LED lamps types listed in Table I. The values in the figures are presented in per unit.

The base value for the voltage, current and active power are determined by

$$V_{base} = V_{nom} , \quad (1)$$

$$I_{base} = \frac{P_{rated}}{V_{nom}} \quad (2)$$

and

$$P_{base} = P_{rated} \quad (3)$$

respectively, where V_{nom} is 230 V (nominal voltage in South Africa) and P_{rated} is the rated power of the lamp being measured.

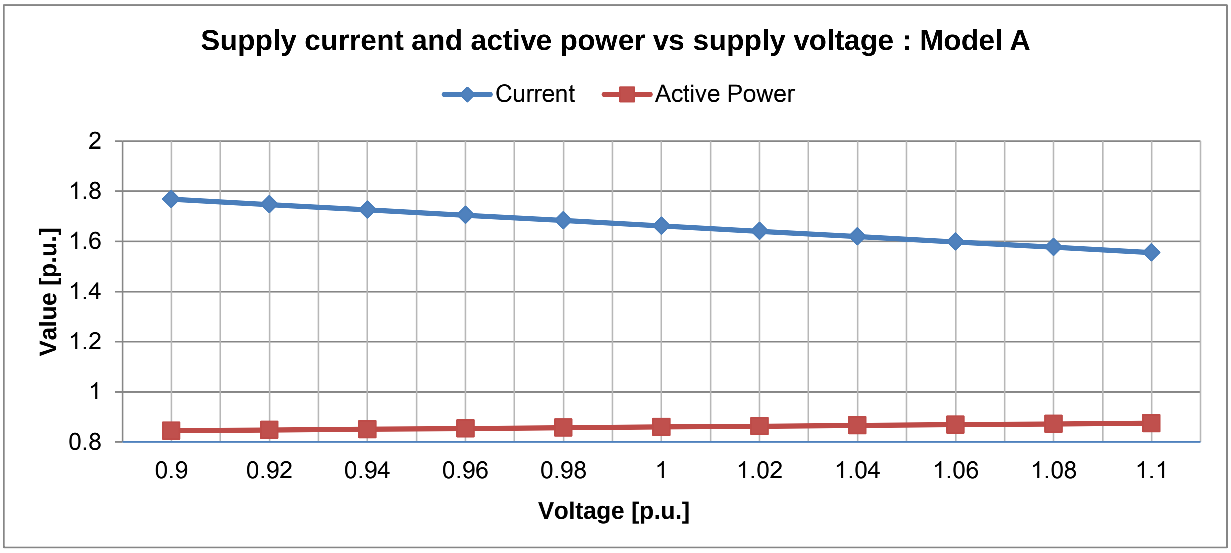

Figure 3: Typical supply current and active power consumption versus supply voltage for the LED lamps of Model A.

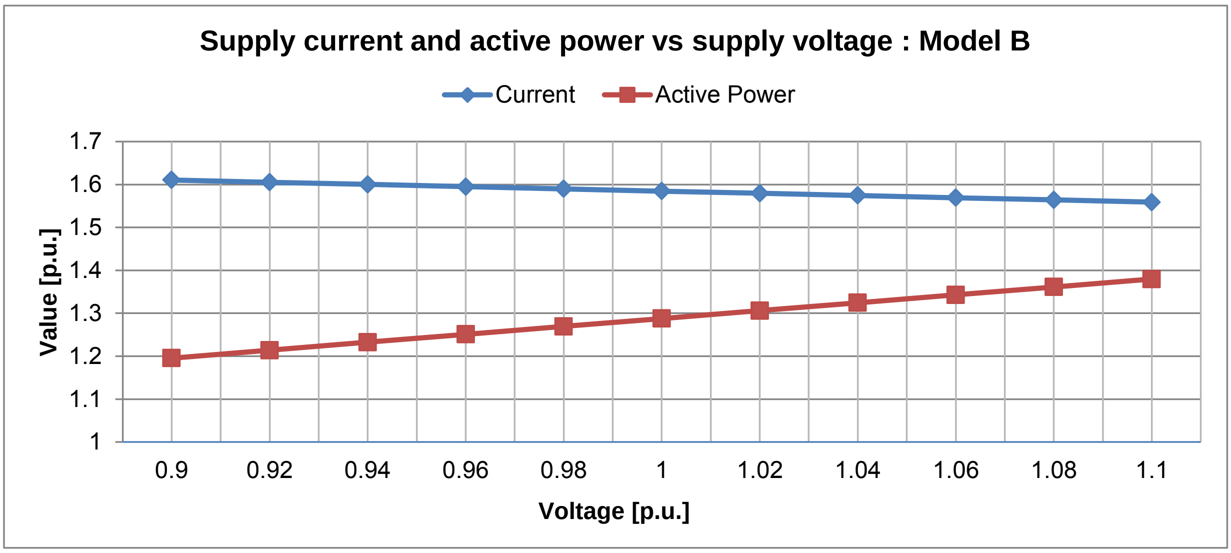

Figure 4: Typical supply current and active power consumption versus supply voltage for the LED lamps of Model B.

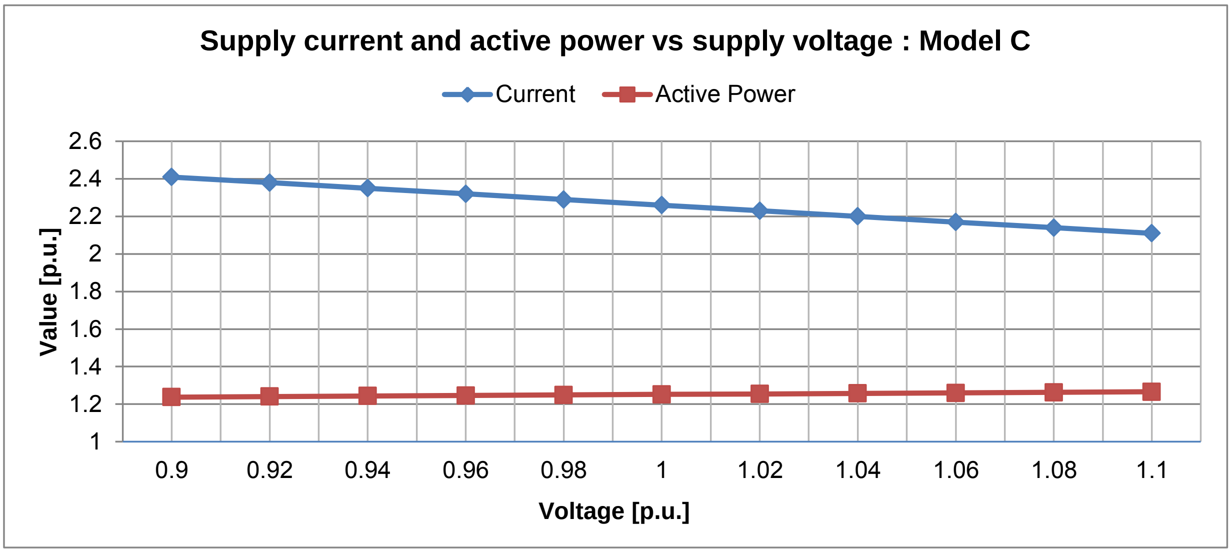

Figure 5: Typical supply current and active power consumption versus supply voltage for the LED lamps of Model C.

Modelling of the voltage dependency of the active power consumption of LED lamps

Samples of LED lamps from the same model that have equivalent power ratings exhibit slight differences in the measured results. The following procedure was used to arrive at a representative model for the active power consumption of LED lamps versus RMS supply voltage for each respective model:

- The measured results for each LED lamp sample are modelled.
- The power consumption over the supply voltage range of interest is determined for each sample from the individual curve derived.
- The average of the power consumption of the test samples are obtained and then modelled with again in order to realize an active power versus supply voltage model for the specific LED lamp type.

Table IV summarizes the models or each of the LED lamp types evaluated. Figure 6 to Figure 8 compare the active power versus RMS supply voltage responses of the regression models to the original measurements obtained for each sample.

Table IV: LED lamps power consumption models

Model	Power Rating [W]	Active power model [W]	R square
A	4	$3.092\times10^{-3}V+2.801$	0.9991
B	3	$1.195\times10^{-3}V+1.160$	0.9997
C	3	$1.183\times10^{-3}V+3.338$	0.9996

Figure 6 to Figure 8 show the active power consumption as a function of supply voltage for each of the samples tested for the LED lamps types listed in Table I. The values are presented in per unit [p.u.]. The base value for the voltage and active power values are as shown in equation 1 and equation 3.

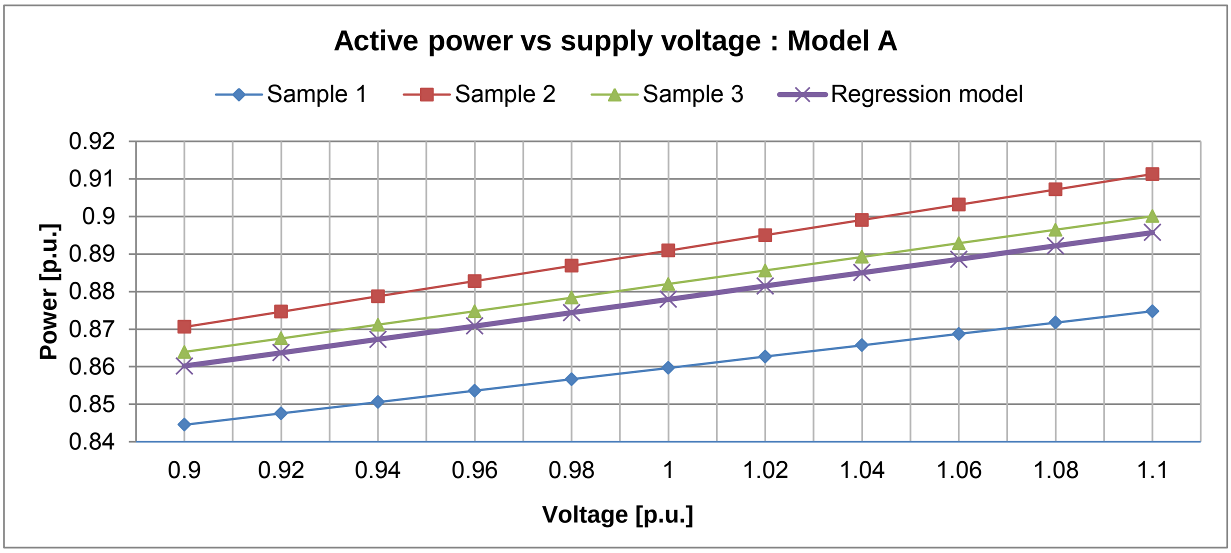

Figure 6: Measured and modelled lamps active power consumption versus RMS supply voltage for the samples of Model A.

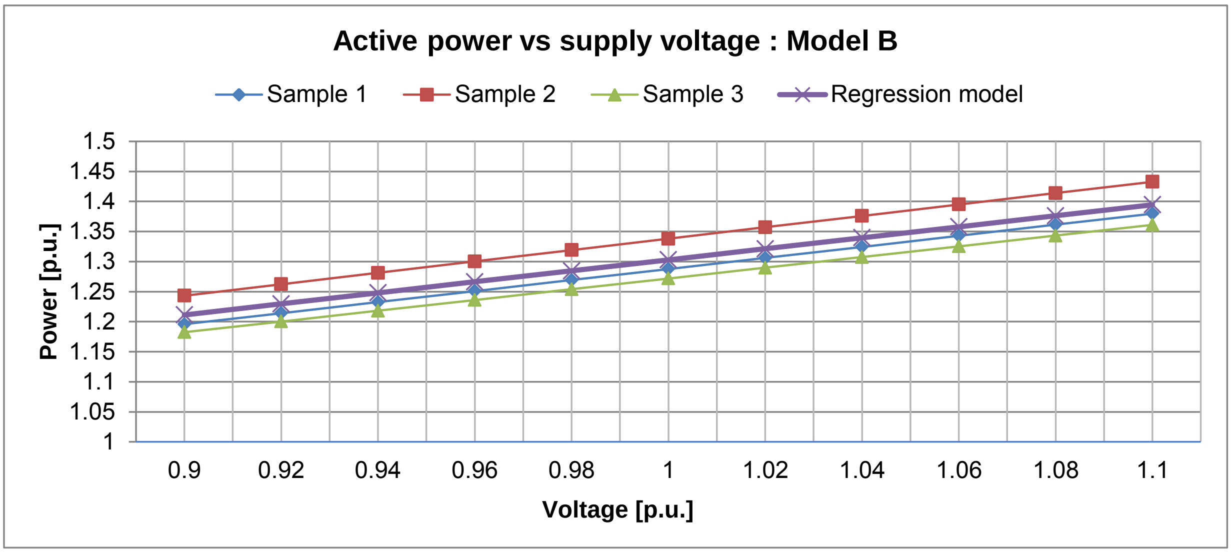

Figure 7: Measured and modelled lamps active power consumption versus RMS supply voltage for the samples of Model B.

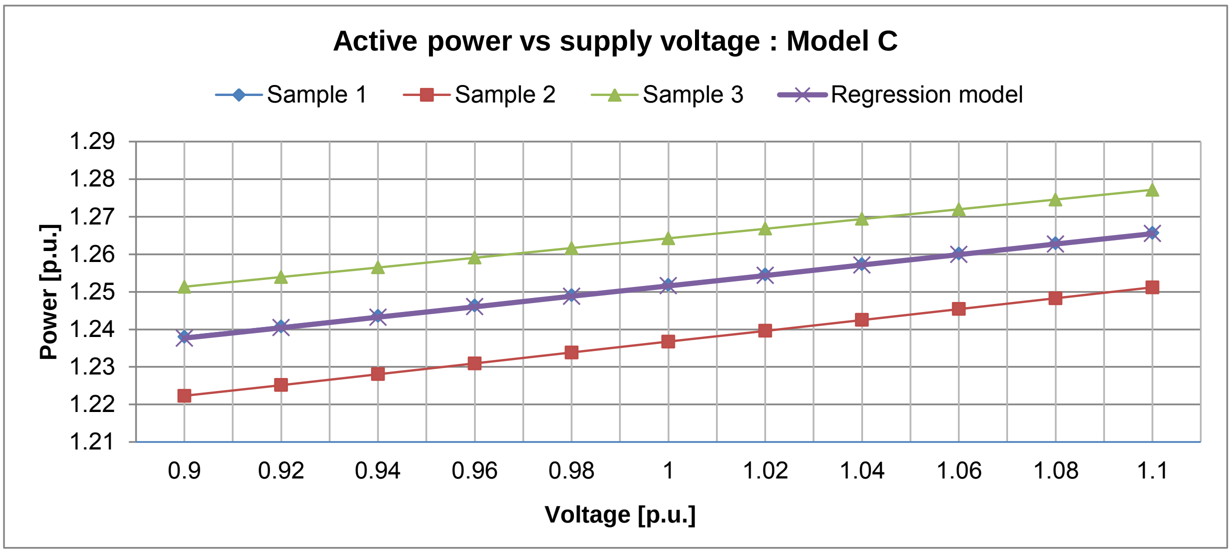

Figure 8: Measured and modelled lamps active power consumption versus RMS supply voltage for the samples of Model C.

Current spectral analysis

Figure 12, Figure 14 and Figure 16 shows a typical example of the current waveforms recorded for the test samples. The current waveforms are highly distorted.

The following two types of spectral results are given for the measured current waveforms:

- Line spectrums graphs that display the amplitudes of the harmonic components versus the harmonic order.
- The Total Harmonic Distortion (THD) of the waveforms is given.

The THD of a waveform is defined as the root of the sum of the square of the harmonic amplitudes divided by the amplitude of the fundamental component of the waveform. This is represented by the relationship

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{N} V_n^2}}{V_1}$$

where V_n denotes the amplitude of the n[th] harmonic, N denotes the highest harmonic order taken into consideration and V_1 denotes the amplitude of the fundamental component [2].

Harmonic Spectral Analysis

The supply voltage and current waveforms were digitized at a sample rate of 50000 samples per second. The Fast Fourier Transform (FFT) as implemented in LabVIEW was used to calculate the frequency spectrum of the transient voltage and current waveforms. The 50000-point FFT yields a frequency resolution of 1 Hz. In the spectral results given below, the amplitudes of the harmonic components spectrum are normalized relative to the amplitude of the 50 Hz fundamental frequency.

Figure 9 to Figure 11 shows the harmonic spectrum of the current waveform for the 3 samples of each of the models considered in this paper.

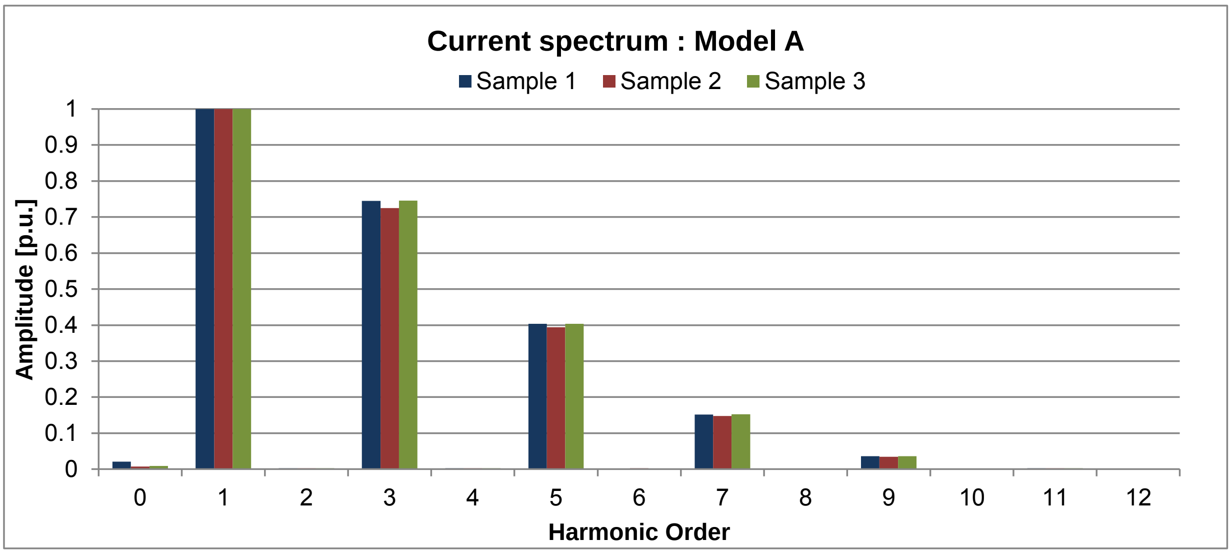

Figure 9: Current spectrum for the 3 samples of Model A.

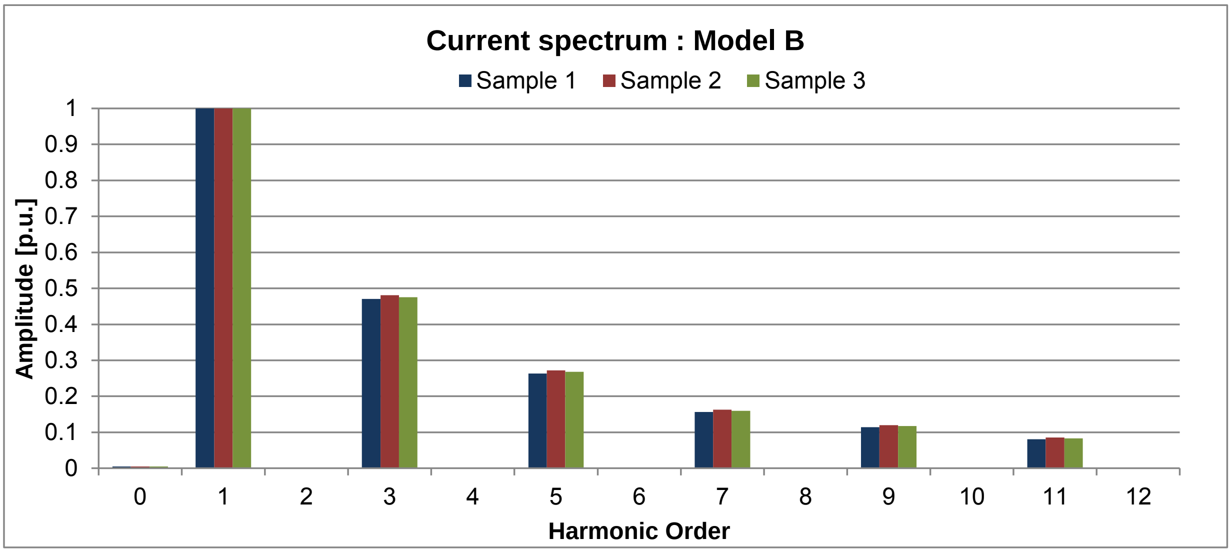

Figure 10: Current spectrum for the 3 samples of Model B.

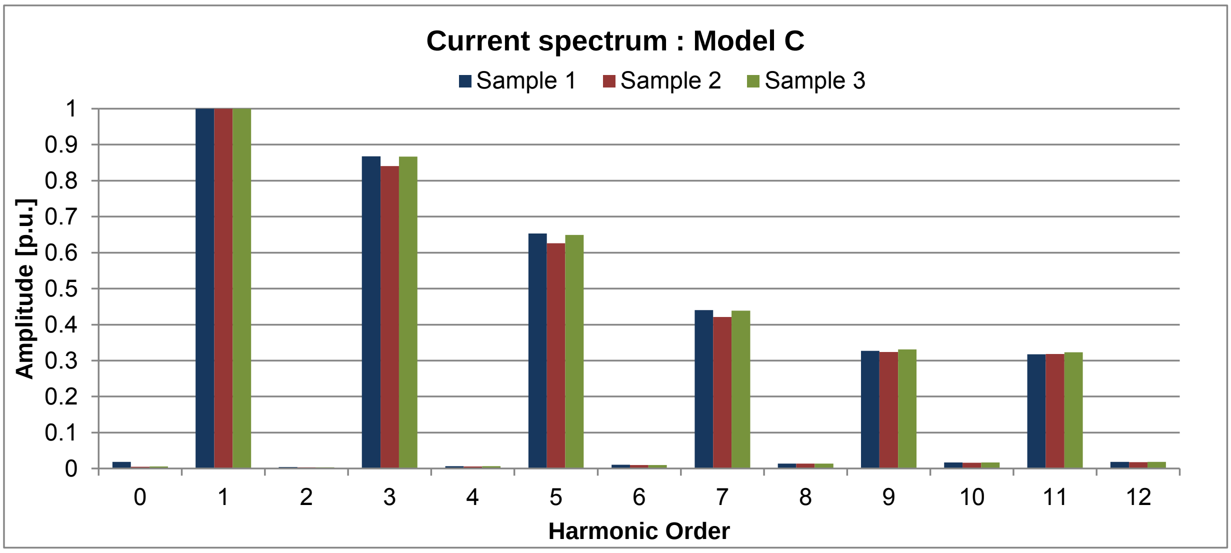

Figure 11: Current spectrum for the 3 samples of Model C.

The current spectrums exhibit large uneven harmonics. Table V illustrates the magnitude of the third harmonic relative to the fundamental for each of the tested LED lamps.

Table V: Magnitude of the 3rd harmonics for sample 1 of the LED lamps considered in this paper

Model	Power Rating [W]	3rd Harmonic [%]	Current THD [%]
A	4	74.51	133.07
B	3	47.04	61.47
C	3	86.80	129.6

Zero sequence currents

One of the most important concerns of harmonic current distortion is the fact that the triplet orders, i.e. 3rd, 6th, 9th etc., represent zero sequence orders. This implies that these current components sum to produce a neutral current in three-phase loads. Measurements were taken in order to illustrate the order of magnitude of the zero sequence harmonic currents. Neutral current measurements were taken using three 40 W halogen light bulbs in order to determine if any neutral currents were present as a result of unknown sources. A neutral current of 5.1 mA was measured. This is possibly due to the slight imbalances of the three-phase supply voltage [2].

Figure 12 to Figure 17 show the results for the three-phase supply current and neutral current waveforms respectively for the LED lamps considered in this paper. The three-phase supply current yields large neutral current component, as expected based on the time-domain and frequency-domain properties of the phase waveforms.

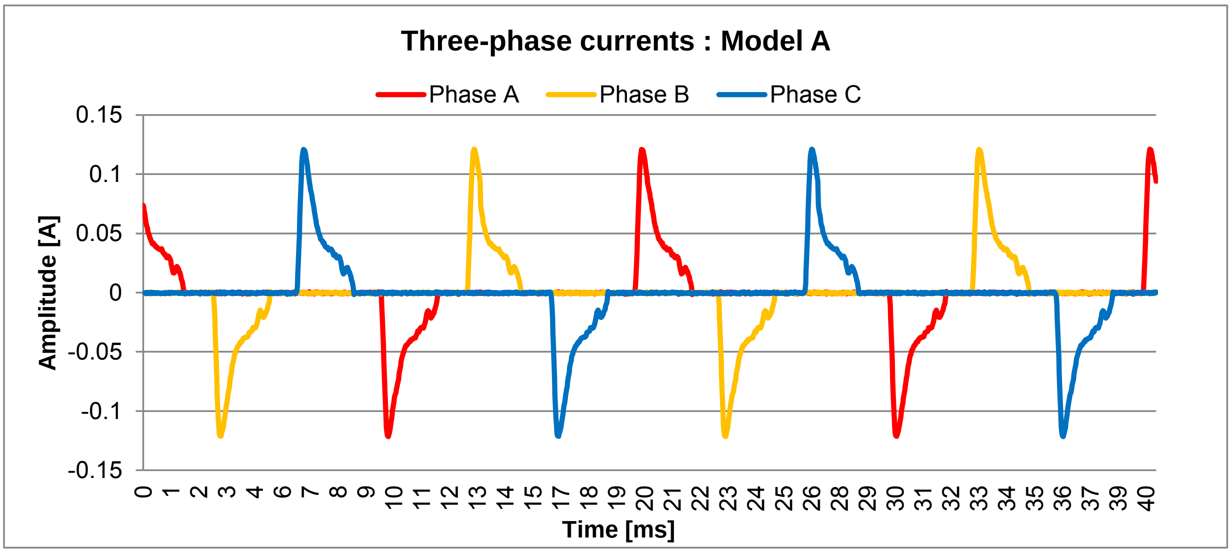

Figure 12: Three-phase current of Model A.

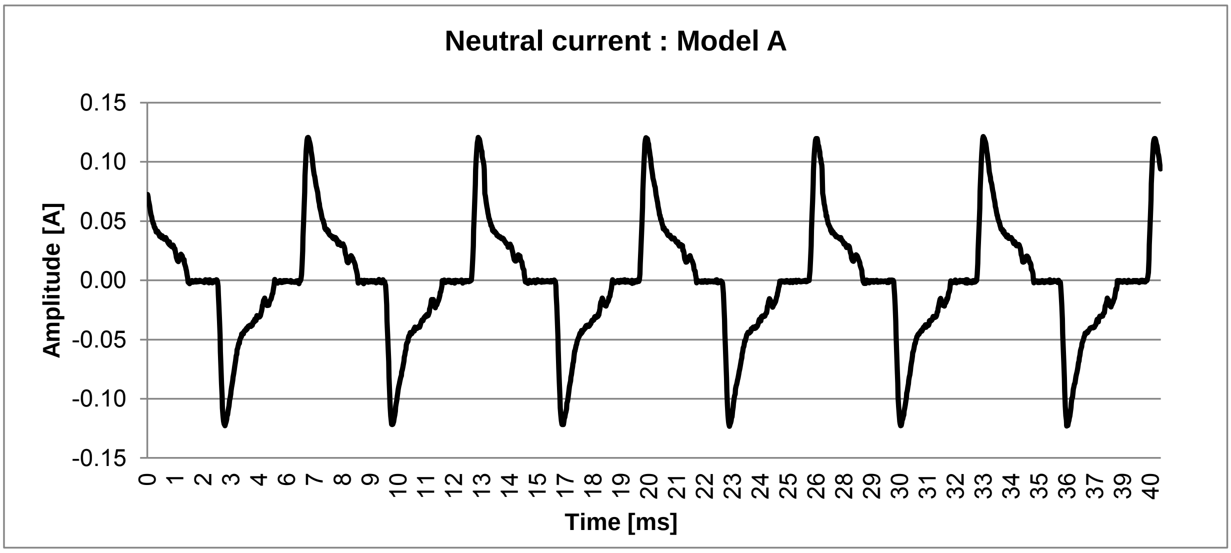

Figure 13: Neutral current of Model A.

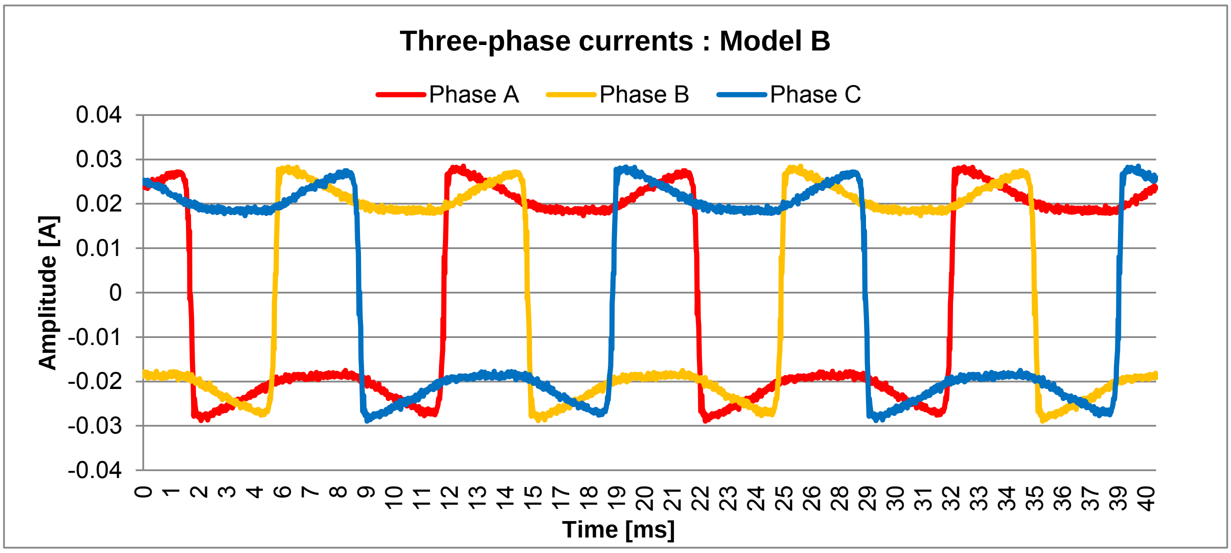

Figure 14: Three-phase current of Model B.

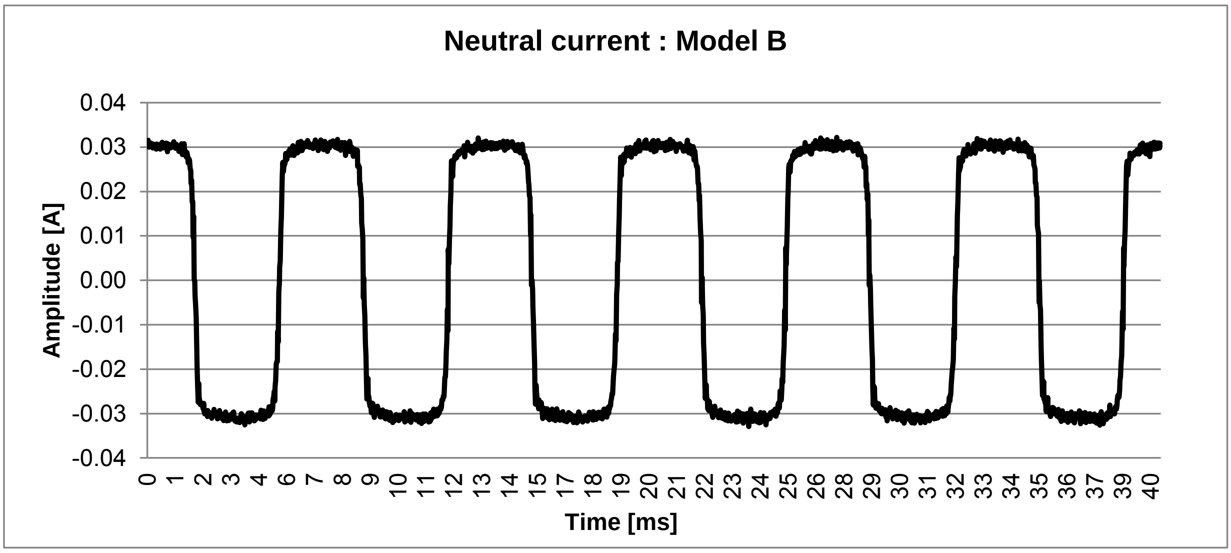

Figure 15: Neutral current of Model B.

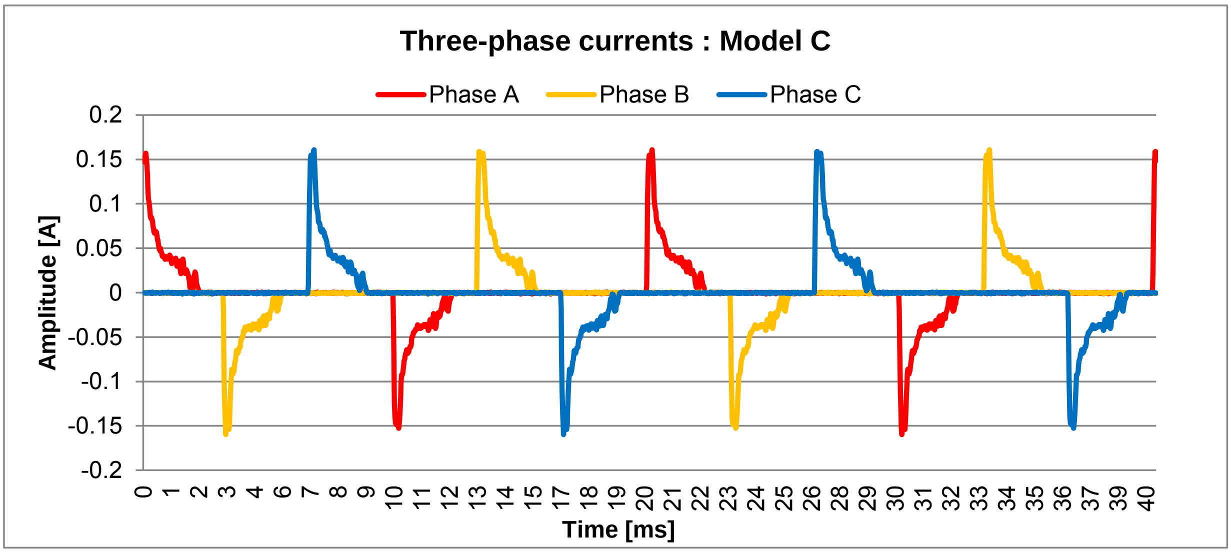

Figure 16: Three-phase current of Model C.

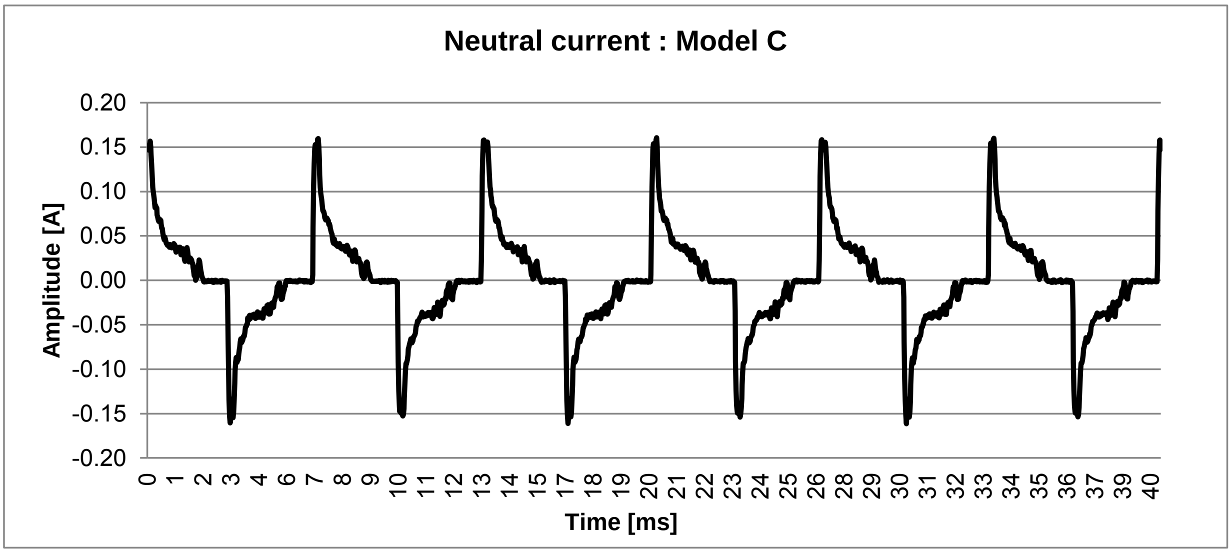

Figure 17: Neutral current of Model C.

Table VI contains a comparison between the phase A currents and the neutral currents of the LED lamps considered in this paper.

Table VI: RMS neutral current vs. RMS phase A current

Model	Power Rating [W]	RMS Phase A Current [mA]	RMS Neutral Current [mA]	RMS Neutral current divided by RMS Phase A current
A	4	27.905	47.897	1.716
B	3	22.343	28.939	1.295
C	3	30.852	54.088	1.753

Conclusions

Voltage dependency

The power consumption of LED lamps as a function of supply voltage magnitude is approximately linear. The power consumption for the LED lamps at 207 V and 253 V respectively are as follows:

- Model A: Approximately 86 % of rated power at 207 V and 89.5 % of rated power at 253 V.
- Model B: Approximately 120 % or rated power at 207 V and 140 % of rated power at 253 V.
- Model C: Approximately 124 % of rated power at 207 V and 126.5 % of rated power at 253 V.

Model A and Model C exhibit an approximately constant active power consumption characteristic, with a less than 4% variation in the power consumption for the voltage range. Model B shows a greater variation in power consumption and exhibits a linear power consumption characteristic, similar to other lighting technologies such as incandescent lamps and compact fluorescent lamps [3].

From an M&V perspective, the variation of the power consumption characteristics of these models can influence the methodologies used to determine the savings impacts of LED lighting interventions, i.e. with models that have an approximately constant power consumption spot measurements at the project site may be sufficient for M&V purposes and for models with a greater variation in power consumption one would have to develop a model based on supply voltage and would have to log the supply voltage of the project site to determine the savings which could increase the cost of the M&V of such an intervention.

Current spectral analysis

The LED lamps supply current waveforms exhibit very high degrees of harmonic distortion, with the THD ranging from approximately 61.47 % to 133.07 % for the samples tested. Harmonic distortion gives rise to additional heat losses in the supply network, especially in distribution transformers [4]. However, because the LED lamps lighting load is small compared to restive loads such as cooking appliances and geysers, the overall impact on QOS is likely to be small [5].

The measured results for three-phase LED lamps loads have shown that the LED lamps give rise to high zero-sequence, i.e. neutral, current loading. This is a potential cause for concern, especially for underrated networks. The practical implications of the increased neutral current loads are increased voltage distortion at the consumer supply points, overheating of neutral conductors and connections, shift of the neutral voltage with respect to earth potential (with possible safety implications) and interference with protection schemes [6]. Overall, the severity of these effects is dependent on the relative LED lamps load rating, actual network ratings and network operating conditions. Most practical networks are likely to contain loads larger than LEDs and therefor the impacts of the neutral currents induced by LEDs are likely to have very little effect.

The results presented in this paper apply for an investigation conducted on the LED lamps referred to in this paper only.

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High quality energy efficient lighting for the domestic sector

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Abstract

New lighting legislation at European Union [EU] level and the fast development of Light Emitting Diode LED technology have been rapidly changing the market of lighting products for the domestic sector. While the classic incandescent lamps have largely disappeared from the market due to the new regulations, Compact Fluorescent Lamps [CFLs] have been improved and LED-technology has been further developed to meet high quality requirements for most applications in households. Nevertheless still many bad lamps are offered on the EU market and it remains challenging for consumers to make a good product choice. The new legislation has made comprehensive declaration of efficiency and quality criteria by manufacturers mandatory, however information criteria are complex and partly irritating for the buyer. A large variety of new products becoming available add to this complexity and many buyers feel discontent and search for guidance.

The IEE project PremiumLight has been designed to support consumers in the selection of efficient high quality products. The measures taken to reach this goal involve comprehensive action with the retail sector aiming at enforced placement and demonstration of efficient high quality lamps at the point of sale and in web-based sales channels. The core activities with retailers are supported by specific information and service tools and by testing of about 80 high quality lamp models. This testing shall confirm the high product quality claimed by manufacturers and provide a basis for concrete recommendations to consumers for LED, CFL and LFL linear fluorescent (LFL) amps.

Results from the product analysis and a basic preparatory research on current buyer behavior are presented. Essential approaches for the market measures are discussed.

1. Introduction

New EU legislation for domestic lighting has strongly influenced the development of the lighting market between 2009 and 2013. The phase-out of the incandescent lamp had a strong impact on market development, in particular the recent development of CFL and LED technologies.

Facing the massive market change with well-known lamp types disappearing and many new lamp models appearing, many consumers felt themselves unguided and uncomfortable concerning the selection of appropriate products for their specific needs. Strong negative media campaigns in several countries against the incandescent lamps phase-out and against CFL technology further increased the uncertainty among buyers. Today, right after the phase-out of the incandescent lamps has been completed consumers find a large variety of LED-products and good quality CFL lamps. Furthermore halogen lamps are still available for applications where a lighting quality similar to standard incandescent lamps is needed.

Nevertheless, despite new EU-legislation, the products currently offered on the EU market still differ significantly regarding quality and efficacy. For the selection of efficient good quality lamps buyers have to consider and understand a number of quality and efficiency criteria. The selection of adequate products from the different technologies is more than ever a demanding task. The initiative Premiumlight was designed to support consumers and retailers in good product selection.

This paper summarizes the results of some essential modules of the project covering among others consumer analysis, product testing and strategy for market measures.

2. Background – New lighting legislation and changing lighting technologies support transformation of the domestic lighting market

2.1 New EU legislation for non-directional and directional lighting and its impact on the market

The market for domestic lighting products has been undergoing a significant change since 2009. In the period between 2009 and 2012 standard incandescent lamps typically used in households have been taken from the market due to new EU legislation [1].The phase-out of incandescent lamps has strongly influenced the market development for the remaining lamp technologies, in particular for LED. In late 2012 additional regulations have been implemented by EC [2], [3] covering directional lamps and a label for all domestic lamp types.

Overall this new legal framework has introduced minimum requirements for lamps sold on the EU-market covering both energy efficiency as well as quality aspects like color rendering, lamp lifetime, switching capability etc.. These criteria allow keeping bad quality lamps away from the EU market. Mandatory information requirements furthermore ensure that the consumer has access to all relevant product information which is to be presented on websites and on product packages. Finally the new label was designed to support consumers in the selection of most efficient products. Thus the new legal framework has provided an essential basis to accelerate market transformation to more efficient products.

Nevertheless the variety of lamp technologies and products available on the market and the number of now accessible efficiency and quality criteria make it more than ever challenging for consumers to select good lamps for various needs in households. While filtering the worst products from the EU-market, the new regulations still leave much room for mediocre product quality and efficiency: the framework still requires that consumers are very well informed about the different technologies and the essential quality and efficiency criteria. The label on the other hand provides a coarse information scheme on lamp efficacy which, however, due to the A+/A++ approach, is less effective as it could be.

Thus summarizing the new EU legislation without any doubts is an essential driver for energy efficient market development in the EU. However the concept leaves some gaps regarding information and stimulation of the demand side market which are to be filled with synergetic measures. The pros and limitations and the resulting need for complementary action can be summarized as follows.

Pros

The new EU legislation

- strongly supports the phase-out of the most inefficient lamp technologies, i.e. incandescent lamps and halogen lamps
- defines essential information criteria for all important efficiency and quality aspects which are now to be declared on lamp packages or on websites.
- provide minimum quality criteria (which however filter only the worst quality products from the market)
- provide new A+/A++ classes which allow a better differentiation of products in the upper segment of the label scale (at least in theory)

Limitations

- The minimum quality criteria filter only the worst products from the EU market. It is thus very important for consumers to be able to distinguish between good and mediocre quality products remaining on the market.

- ➢ The now available comprehensive product information provided on the lamp packages and in web-based product information requires quite good knowledge of buyers. Consumers need to be able to interpret the information to take a good product choice.
- ➢ The label concept is coarse and with the A+/A++ approach not optimized to have a strong impact on the consumer, thus it is to be complemented with additional information measures.

2.1 Technology development – diverse market with different technologies and many different products CFLs further increases the challenge for consumers

LED technology for both domestic and professional lighting has been strongly improved within the last four years. Today almost all typical lamp types in households can be replaced with adequate LED lamps. Luminous flux of the most powerful LEDs is already higher than the flux of 75W standard incandescent lamps and regarding major quality and efficiency criteria like color rendering, lamp life time and efficacy, LEDs have already have been passing levels of CFLs. Color rendering values of 90 and above, average lifetimes above 25000 hrs. and efficacies of more than 80lm/W are declared for the best products.

On the other hand there is still the barrier of high production costs and high prizes. Efficient good quality LED lamps still cost between 20 and 40 € which is double the price of CFLs. Thus the selection of a LED for economic reasons only makes sense if double lifetime is provided.

Overall considering prices and types of applications LED is not necessarily always the better choice compared to a CFL. LEDs certainly are certainly to be preferred for applications where no warm-up time is acceptable and mercury in the lamps is to be avoided or where dimming is required (broad variety of dimmable LEDs). Furthermore LEDs provide a very competitive alternative to halogen spots, offering ten times longer lifetime and three times higher efficiency at comparable light quality.

Types and shapes of lamps from the major technologies halogen, CFL and LEDs are manifold and it is challenging for consumers to understand the advantages of different lamps and make a good product choice.

3. Current buyer behavior and some consequences for consumer information measures

3.1 Short consumer analysis supporting the design of project measures

A short consumer survey conducted as part of the PremiumLight project was designed to get some insight into essential aspects of current buying behavior. The survey was designed as a limited “screening” approach involving a total of 500 consumers per country. The survey was based on a questionnaire covering questions on typical consumer preferences and aspects relevant to buying behavior. Interviews were limited to 20 min per person.

The following chapter shows only selected results of the investigation covering issues like the typical lamp types currently used in households, main lamp selection criteria as well as typical information and purchasing channels.

3.2 Results from the analysis

Lamps used in households

As a first indicator of current buying and usage behavior, the average number and types of lamps in households have been analyzed. Fig. 1 provides a summarizing overview on the data for the different countries. The average total number of lamps currently used in households varies between 20 and 35 in the different countries. While in countries like Austria, Denmark and Sweden typically more than 30 lamps are installed, other countries like Czech Republic, France, Latvia and UK reported lower numbers close to 20 lamps per household. However it has to be considered that the bare installation numbers do not give an indication of real usage of lamps and luminaires. Even if in some countries typically more luminaires are installed, some of this luminaires may only rarely be used. The specific investigation did only include a rough analysis of the usage intensity indicating that depending on the country about 30-50% of the lamps in the households are rarely used. No differences regarding usage intensity of different lamp technologies have been detected.

Still more interesting is the share of different lamp types which also indicates the average level of lighting efficiency already achieved in the households. Even after the complete phase-out of the standard incandescent lamp in fall 2012 a significant percentage of lamps in households still belong to this category. Shares of this lamp type in households range from 16% in Italy to about 42% in Latvia. This indicates that households still support stocks of incandescent lamps and it will still take some time until this low efficiency technology is completely removed from the market.

Concerning halogen lamp technology which is only slightly more energy efficient than classic incandescent technology the data shows the following situation. Halogen bulbs which have been introduced as replacement for classic incandescent lamps are still relatively rare, accounting for 5-10% of lamps in all countries (typically 1-3 lamps per household). On the other hand halogen spots are quite more common with shares between 10% and 28%. Halogen sticks (R7s) are used more frequently in Austria, Germany, Italy and Spain and are less abundant in the other countries. Although also in Austria, Germany, Italy and Spain only one lamp of this type per household is typically used, this may have a strong impact on overall lighting efficiency for the specific households. Halogen sticks are high power lamps rated 150-300W typically used for uplighters in living rooms. Thus one such lamp may use the same power as 10 CFL or 15 LED lamps and are often heavily used for several hours per day.

Overall the share of non-efficient lamps which include standard incandescent lamps, halogen spots and halogen bulbs ranges between 38% and almost 60% in the different countries. Consequently the potential for energy savings is still huge.

Regarding the use of lamps with fluorescent technology the number of installed lamps respectively the percentage of installed lamps also varies significantly between the different countries. The percentages range from 25% to 50%. In several countries also including the southern countries Italy, Spain and Portugal fluorescent lamp technology is quite well accepted while in other countries like Germany and Austria there are still more prerequisites against the technology.

Finally regarding LED lamps the results clearly show that the share of this technology is still low. The number of lamps per household ranges from 1% to 15% in the different countries. Most LEDs are currently used in Sweden, Portugal, Germany and Austria. Thus the potential for this technology clearly is high and currently mainly limited by high purchasing price.

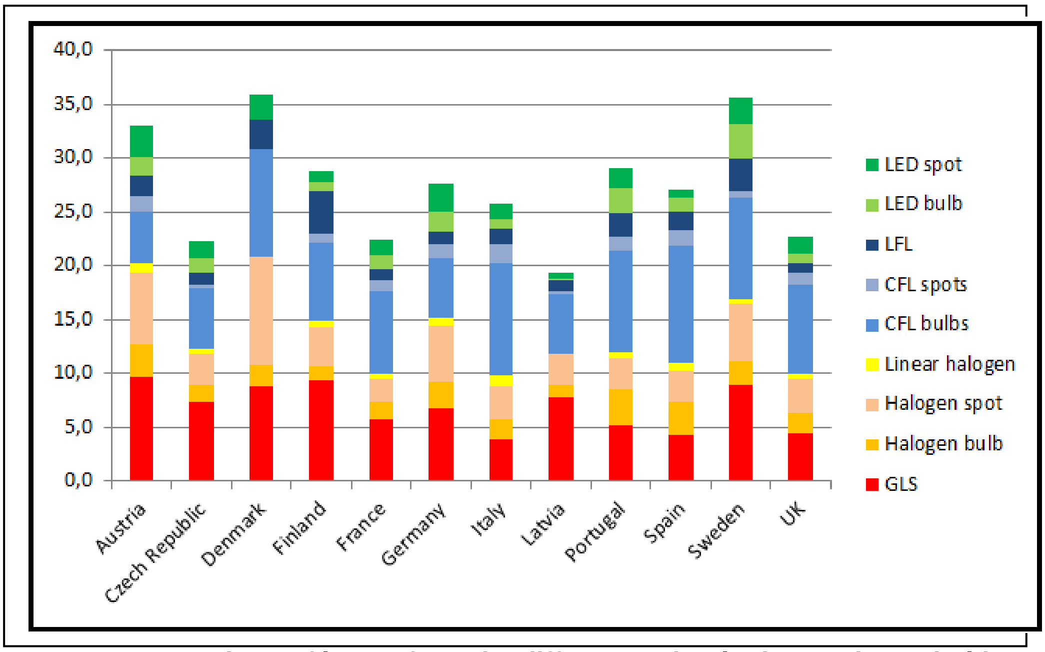

Figure 1. Average numbers of lamps from the different technologies per household

Relevance of different criteria for lamp selection

Another aspect particularly relevant for the project is the criteria for lamp selection. In this context the project analysed the relative relevance of purchasing criteria like brand type, purchasing cost, lifetime, light color etc. in order to evaluate the specific key aspects primarily considered by the buyer.

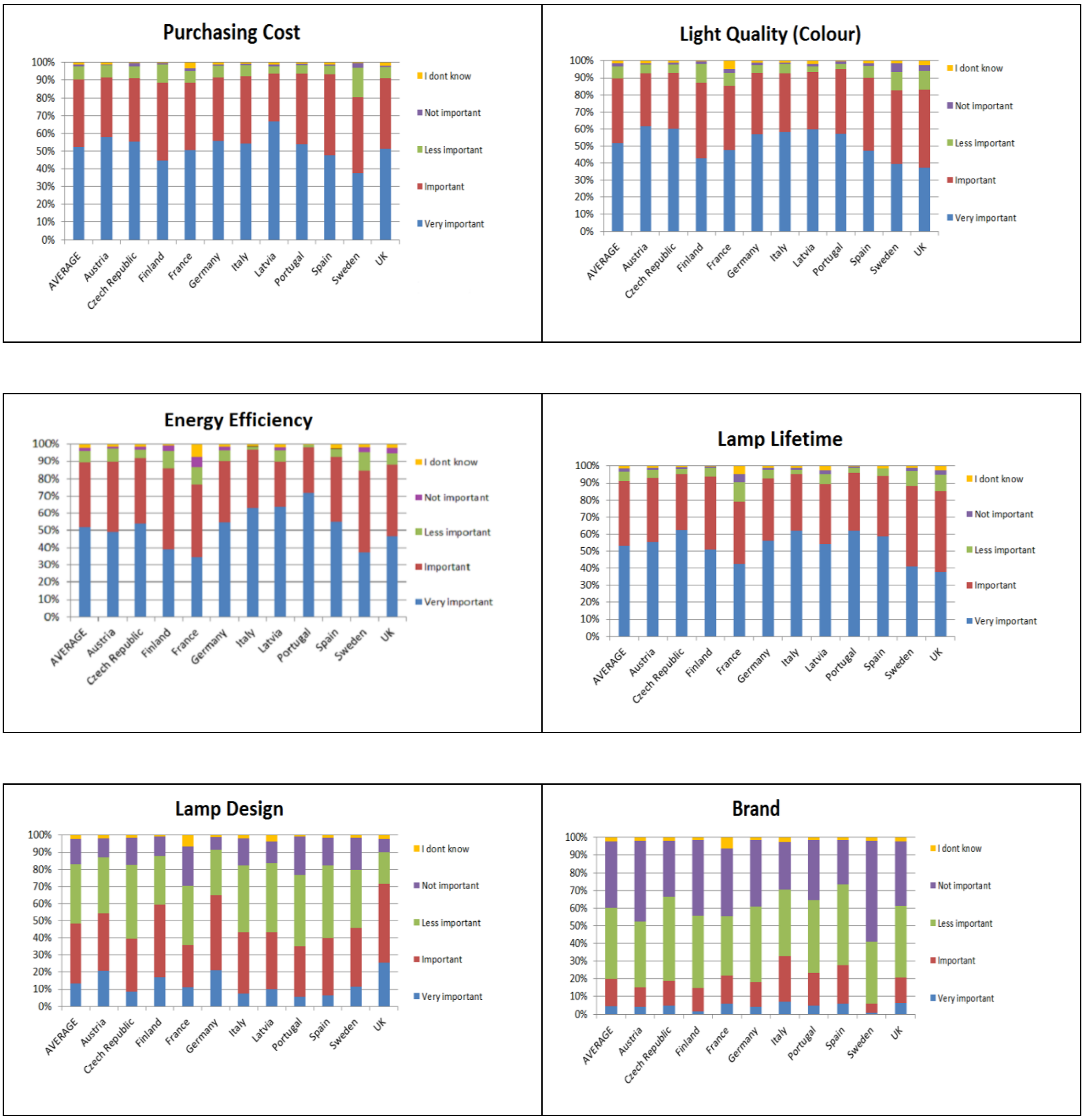

Fig.2 Importance of different lamp criteria from the buyers perspective in the different countries

Fig. 2 shows some of the survey results clearly indicating that purchasing price, light quality, lamp lifetime and energy efficiency (in parallel to operating costs, which is not shown) are of high or very high relevance for the buyers. On the other hand lamp brand, for example, is generally of little importance. Also lamp design is of limited importance for many buyers except for UK, Germany and Finland.

Information sources and purchasing channels for lamps

Knowledge on purchasing channels and information sources of consumers provides a central basis for the development of adequate information and communication measures. In the short survey buyers were asked about their specific habits for purchasing lamps. They were first of all asked about the primary purchasing channels (selection of multiple important channels was allowed). Second they were asked to indicate the most used information channels.

Fig. 3 on typical buying channels shows that many consumers in the different countries are used to buy their lamps in super markets or simple grocery stores. This means that purchasing of lamps typically goes along with daily purchasing of groceries.

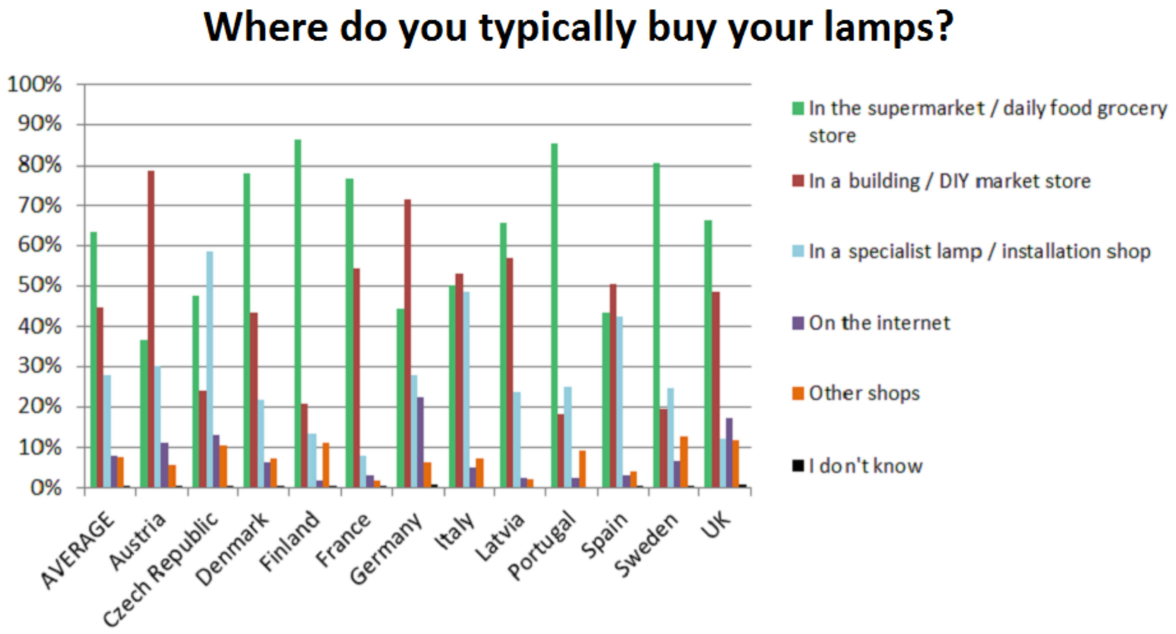

Fig.3 Typical sales channels for lamps in the different countries

In most countries 60-80% of the consumers indicate that supermarkets and grocery stores are of major importance for lamp purchases. In many countries lamps are also bought in building and do-it-yourself shops. 40-80 % of the consumers in these countries indicate these shops as very important for lamp purchases. Particular importance is indicated in Germany and Austria. On the other hand the relevance of specialized electronic shops is much lower with higher importance reported only from Czech Republic, Italy and Spain (highlighted by 40-60% of the consumers). In all other countries significant relevance is only indicated by less than 30% of the consumers. Sales via the internet besides Germany are mostly below or close to 10% and therefore rather negligible

Overall the buying patterns in the different countries have some significant relevance also regarding the demand of the different technologies. While supermarkets and grocery stores typically have sold low cost incandescent and halogen lamps the variety of energy saving lamps and LEDs is mostly small. Thus buyers mainly relying on supermarkets and grocery stores will have more difficulty in switching from old inefficient technology to energy saving lamps and LEDs. Variety of efficient lamps in do-it-your-self shops is generally much better.

Overall for a powerful communication strategy this means that both grocery stores/supermarkets and do-it-your-self stores are quite essential elements for effective promotion respectively for reaching a significant part of the target groups. However in the case of super-markets first of all the typical product assortment has to be influenced.

Concerning the primary information sources of consumers Fig. 4 provides some indication on preferences in the different countries. While the internet is a primary most important information source in all countries the relevance of other information channels is quite different from country to country. In some countries like Austria, Germany, France, Latvia, UK the relevance of information in do-it-yourself and building stores is quite high, while consumers in Portugal, Sweden, France, UK and Finland also claim high relevance of the information provided in super markets and grocery stores.

For strategic information purposes this means that information via web services is generally a very effective means for promotion and communication. For the other sales channels the relevance differs from country to country. Furthermore it is noticeable that a significant percentage of buyers reported that they do not know where to inform themselves about lamps. In seven of the countries 20-30% of the buyers indicated that they do not know where to be informed about lamps. Thus a significant share of the consumers is still to be reached.

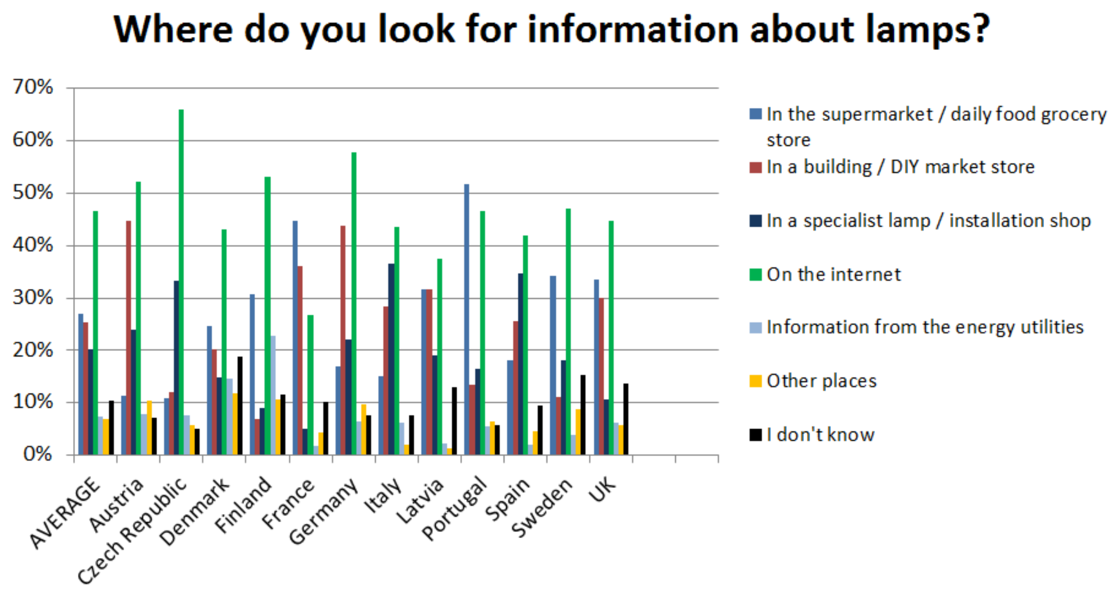

Fig. 4 Typical information sources for buyers of lamps

4. Assessment of product quality and efficiency of LEDs

The PremiumLight initiative also has a focus on providing guidance to efficient high quality products. For this purpose also product testing of declared efficient high quality lamps is conducted. Selected LED products from the upper quality and efficiency segment of the EU market are tested to verify promised performance levels. It is not a goal to test average or lower quality products or to do market surveillance in terms of the EU-regulations. For the selection of lamps from the upper quality and efficiency segment concrete criteria had to be defined which are described in the following chapter.

4.1 Quality and efficiency criteria

Product tests covered both directional and non-directional lamps typically used in households. Spot lamps included both high-voltage and low voltage lamps. It was a priority to select rather powerful lamp types and lamps that are the most advanced and relatively new on the market. Second, concrete criteria have been set in terms of colour temperature, colour rendering and lamp lifetime. The criteria are listed in the table 1. Regarding light colour and colour rendering only “warm-white” lamps with a colour temperature between 2600 and 3500K have been considered. Minimum colour rendering was Ra80 (f LED lamps with lower Ra are allowed on the market until fall 2013). The minimum declared lamp-lifetime was 20000 hrs. The minimum luminous was 200lm for spots and 400lm for bulbs. Thus typically lamps serving as replacement for 30-50W halogen spots and for 40W-75W bulbs were tested. Minimum efficiency was defined as 55lm/W for bulbs and 45 lm/W for spots with an exception for IKEA lamps which were included in the sample due to their abundance and frequent use.

The lamp sample included 3 tested lamps per sample and testing results are provided as average values from the three tests. For the initial test conducted in early 2013 only the parameters luminous flux, colour rendering, colour temperature, efficacy and power factor have been considered. The criteria lumen maintenance and switching cycles are part of the long-term tests with a first evaluation in fall 2013. Testing of the different criteria has been based on the available relevant standards.

Market surveillance testing is typically done with 20 lamps per lamp model. Thus this specific testing has not been designed as market surveillance but the results are also used as a type of pre-screening of products.

Table 1. Minimum values for the selection of tested lamps

	LED-Bulbs	**LED-Spots**
Color temperature	2600-3500	2600-3500
Color Rendering	>80	>80
Luminous Flux	>400	>200
Efficacy	>55lm/W	>45lm/W
Lamp-Lifetime	>20000	>20000

4.2 Selected results from the initial testing period

Tables 2 and 3 provide a summary of the initial measurements for luminous flux, colour temperature, colour rendering, efficacy and power factor for both bulb-shaped and spot lamps. Both measured data and data declared by manufacturers (in brackets) are shown. Long-term testing also including indicators for lamp-lifetime (e.g. lumen maintenance and switching cycles) is continued until fall 2013 with results being reported before the end of the year.

Overall the results from the initial testing were quite promising. Test results for the well-known brands for several products were even better than the declared values. In contrast for a few less known brands there was a contrary tendency.

According to the test results and in agreement with the product declarations all lamps provided warm-white light colour (between 2600k and 3200K) with only moderate deviations from the declared values.

The representation of light colours was mostly good and very good for a few models. The majority of the lamps showed colour rendering values between Ra80 and Ra85. Very good colour rendering was provided by two bulb-type products from Swedish and Austrian manufacturers, which both offer lamps with Ra 90. On the other hand part of the lamps with good colour rendering showed comparably low efficacy below 50lm/W. Lamps from one no-name brand showed low colour rendering of Ra 70 which is not desirable for indoor lighting and will not be allowed anymore by EU legislation after fall 2013.

Regarding brightness and energy efficiency most products showed quite good testing results largely in agreement with the declared product data. Energy efficiency was mostly above 60lm/Watt for bulbs and close to or above 50lm/W for spots. Unfortunately the lamp model with the highest measured efficiency (86 lm/W) could not comply regarding colour rendering requirements.

Only two lamp models showed dramatically lower luminous flux compared to manufacturer declaration. A measured flux of 24-33% below declared values is not acceptable from the consumer perspective.

Besides the quality and efficacy parameters also the power factor has been measured for most lamps. While not being a direct quality criterion for consumers, a low power factor typically has a negative impact on the grid. There has been significant debate in the eco-design process for domestic lighting to what extent minimum requirements for the power factor shall be considered. The current definitions require that lamps below 5W power will need to have a power factor >0,4, lamps above 5W a power factor of >0,5. As the data indicates not all lamps from the test would comply with this new requirements.

Overall the test results show that most lamps especially from the well-known brands provide good quality and efficiency and are in agreement with the manufacturer declarations.

Tab.2 Declared and tested values of key parameters for non-directional LEDs (bulbs)

	Type	Luminous Flux [lm]	Power [W]	Power factor	Efficacy [lm/W]	Color temperature [K]	Color rendering index CRI
AustroLed	G50 clear bulb	416 (550)	4.8 (6)	0.44	86.1 (91.7)	2,983 (2,700)	70 (80)
Philips	LED 11W	861 (806)	10 (11)	0.57	85.8 (73.3)	2,673 (2,700)	80.7 (80)
Osram	Parathom Classic A 75	1,063 (1,055)	13 (14.5)	0.96	82.0 (72.8)	2,727 (2,700)	80.2 (80)
V-Light	Bulb	763 (810)	9.5 (10)	0.88	80.2 (81)	2,851 (2,700)	87.7 (85)
Philips	Master LED Bulb	1,248 (1,055)	16.3 (17)	0.71	76.4 (62.1)	2,673 (2,700)	81.1 (80)
Samsung	LEDA19	718 (650)	9.4 (10)	0.94	74.9 (65)	2,823 (2,700)	80.3 (80)
LEDON	G95 (Globe)	662 (600)	9.4 (10)	0.81	70.2 (60)	2,660 (2,700)	89.4 (90)
Bioledex	LIMA 17W	1,095 (1,200)	16.1 (17)	0.83	67.9 (70.6)	2,883 (2,900)	85.1 (85)
MegaMan	LED Classic, MM21015	699 (620)	11.3 (11)	0.69	61.9 (56.4)	2,857 (2,800)	79.9 (80)
MegaMan	LED Classic Professional, MM21016	720 (810)	11.8 (11)	0.68	61.2 (73.6)	2,887 (2,800)	80.4 (80)
IKEA	LEDARE Clear bulb	397 (400)	7.4 (8.1)	0.55	53.5 (49.4)	2,559 (2,700)	92.5 (85)
IKEA	LEDARE Frosted Bulb	384 (400)	7.5 (8.1)	0.55	51.1 (49.4)	2,662 (2,700)	93.6 (85)

Tab.3 Declared and tested values of key parameters for directional LEDs (high-voltage and low voltage spot lamps)

Brand	Type	Light output [lm]	Power [W]	Power factor	Efficacy [lm/W]	Color temperature [K]	Color rendering index CRI
V-Light	Spot (GU10)	356 (380)	5.7 (6)	0.67	62.6 (63.3)	2,863 (3,000)	78.3 (80)
Philips	Reflektor 6.5W, (GU5.3)	409 (380)	6.6 (6.5)	-	62.2 (58.5)	2,690 (2,700)	84.8 (80)
Philips	Master Spot (GU10)	210 (165)	4.0 (4)	0.60	52.6 (41.3)	2,900 (2,700)	82.9 (80)
LEDON	7W LED (GU10)	314 (320)	6.1 (7)	0.41	51.5 (45.7)	2,813 (2,700)	84,6 (80)

Osram	LED Superstar PAR16 (GU10)	252 (200)	5.1 (5.5)	0.47	49.4 (36.4)	3,043 (3,000)	80.8 (80)
Barthelme	LED Spot MR 16 (GU5.3)	238 (315)	4.9 (6)	-	48.9 (52.5)	2,940 (3,000)	81.5 (80)
AustroLed	LED Spot MR16 (GU5.3)	263 (400)	5.5 (6)	-	47.5 (66.7)	3,120 (3,000)	81.4 (80)
TOSHIBA	Spot (GU10)	282	6.1 (6.5)	0.92	46.3	2,673 (2,700)	80.7 (80)

5. Strategic concept of PremiumLight to support the demand-side market - Cooperation with retailers

5.1 Simplicity and clearness in consumer information

In the introductory section it has already been outlined that the current market situation and EU legal framework and information policy still leaves some challenges for the buyers to select high quality efficient lamps for the specific individual needs. Eco-design and labelling regulations have improved the situation by removing the worst products from the EU market and by providing a rough indication of the energy efficiency of products. However the framework leaves still leaves much room for very different levels of product quality and efficiency and it remains still a challenge to select adequate high quality lamps for specific purposes. Consumers need to be familiar with the advantages and disadvantages of the different lamp technologies and need to be able to interpret the most important quality and efficiency criteria:

Thus the PremiumLight-Initiative is strongly focusing on the following goals to support the demand side market:

- Making the most important product criteria easy understandable for the consumer and visible at the point of sale
- Inform the consumer of the advantages of the different lamp technologies and their suitability for different applications in a simple and transparent way.
- Inform and train retailers and enable them for effective consultation of consumers
- Promoting good products based on product testing

5.2 Education and information of retailers and consumers

Information and education of retailers is achieved with new information tools focusing on the essential information on lamp technologies and quality parameters for a good lamp selection. For this purpose the following major measures are taken:

- A new type of information material (both digital and printed versions) is made available for both retailers and consumers focusing on the essential technology and criteria information linked to typical lighting applications in households
- Consumer information is supported by specific demonstration and visualization measures in shops
- Knowledge of sales personnel is supported by web-based training tools
- Additional tools concerning operation costs and incentives for purchases of energy efficient equipment are implemented.

The full roll-out of activities is done between summer and winter 2013 with major actions still continued until in 2014.

6. Conclusions

The results of the market analysis have shown that many consumers in the EU-countries were used to buy their lamps in grocery stores and supermarkets together with their daily purchases. In the age of the incandescent lamp standard 40-75 watt light bulbs were the typical most common light source in households. Thus the few lamp types from the major brands typically offered in grocery stores and supermarkets often were sufficient to meet the common needs for household lighting. Today the market has completely changed and a large variety of lamp types especially LEDs from different brands and of different quality are offered on the EU-market. Thus the consumer should consider that buying good lamp products requires more information but potentially also a change of the source respectively the type of shops where the products are purchased. Today it is clearly more effective to buy lamps in shops where more expertise and variety is provided such as in special electronic shops, electronic retail chains or do-it-yourself shops.

The investigations furthermore indicate that consumers in the EU countries are aware of the different essential criteria to be considered for lamp purchases including luminous flux, light colour, lamp lifetime, colour rendering and efficacy. However it is still essential to educate consumers and retailers about the proper criteria levels that make a good lamp. The product range currently offered on the EU-market especially for LEDs still includes quite different quality e.g. products with low lamp lifetime e.g.10000hrs or even below or a colour rendering of Ra<80. Thus a careful product selection by the consumer is quite essential.

Rather little attention is currently spent on lamp design and lamp brands. However both of these aspects have become much more important today as especially for LEDs quite different designs from a large number of manufacturers are sold. Lamp quality may differ significantly between different designs and manufacturers.

Lamp tests conducted as part of the PremiumLight initiative have been focussed on LED technology and primarily on the goal to test and finally recommend good quality lamps. Thus the specific tests do not allow conclusions on the average quality of LED lamps. For the tested premium segment of both non-directional lamps and directional lamps the tests showed an overall good product quality. Only few lamps from the sample showed lower quality respectively failed to comply with the declared quality or efficiency criteria. However some long-term tests providing more information on lifetime related aspects like lumen maintenance are still continued and will finalize the comprehensive assessment of the products.

References

[1] EC: COMMISSION REGULATION (EU) No 1194/2012 of 12 December 2012,implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for directional lamps, light emitting diode lamps and related equipment.

[2] EC: COMMISSION REGULATION (EC) No 245/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council

[3] EC: COMMISSION DELEGATED REGULATION (EU) No 874/2012 of 12 July 2012 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labeling of electrical lamps and luminaires

Going down the efficiency road for domestic lighting: Detailed assessments of possible savings in one-person households by new, efficient lighting solutions - a study based on measurements and health aspects

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Topic: Measurement Methods and International Harmonisation; End-use Metering and Home Automation; Program and Policies Monitoring & Evaluation

Key words: Lighting, EcoDesign Directive,Energy labelling Directive, campaign results, monitoring and evaluation, consumer behaviour

Abstract:
The aim of this paper is to is to explore possibilities of decreasing energy consumption of lighting using the data collected in an in-depth measurement campaign. For the purpose, one-person households are chosen since it is only in this type of household the effects of occupancy control can be shown. Furthermore, one-person households are also becoming more and more common so they represent a significant part of all households.

The Swedish energy agency carried out an extensive measuring campaign during 2005 - 2008 in apartments and detached houses in order to measure most of the end-use equipment in ordinary homes, with respect to energy use, user patterns, etc [Zimmermann, 2009]. Previous reports from this study have shown that lighting is one of the most dominant end-uses; more than 20 % of the domestic use of electricity is from lighting, particularly incandescent light bulbs.

This study uses the full potential of the vast lighting data collected which allowed to analyse where and which lighting technology is used and how it is used by the consumers in different dwellings, room types, etc.

- The study comprises of four steps: retrofit of incandescent light sources with CFLs and LEDs retrofit of halogen lights with LEDs; introduction of more lighting controls; and adaptation of light levels to our circadian rhythm by dimming techniques for one-person households. In the first step the incandescent light sources were replaced by efficient lighting. LED based retrofits have developed rapidly in the past years and provide more and more of these alternatives up to correspondingly 60 W incandescent lamps.
- In step two halogen lights were replaced with LED retrofit lamps.
- In step three the possible savings by using more lighting controls have been assessed.
- In the final step an attempt to assess the savings by adapting light levels to our sleeping (circadian) rhythms by dimming techniques have been done.

The final result is a household lighting giving the same comfort as before or even better taking the circadian rhythm into account. At the same time energy consumption is reduced from 333 kWh per year to 60 kWh, which corresponds to a reduction of 82 per cent. Part of this reduction has been already been achieved with the ecodesign ban on sales of incandescent lamps. However as halogen lamps in many cases have replaced incandescent lamps the full potential of replacement is not yet there.

1. Introduction

1.1 Ecodesign

The ecodesign regulations for non-directional lighting[1] have been in place since 2009 and the last exemption for incandescent-based lamps was removed in 2012. The same year the new regulation on directional

[1] Regulation 244/2009

lighting and LED lamps[2] and energy labelling for all kinds of lamps[3] were adopted (although they come into force 1 September 2013 at first), finally putting requirements of this so-far only partly regulated lighting products. The phase-out of the incandescent bulb is therefore almost complete and new lighting solutions, not least based on LED-technology, is taking over at a rapid pace.

Following the implementation of the new regulations, an interesting task for governments is to explore whether the expected savings potential (at least 39 TWh annually from 2020) will be realised, or if, for instance, rebound effects will offset these savings. Possible effects include unforeseen lighting systems combined with altered user patterns. Thus, in order to analyse the change in technology and use of lighting, it is important to know the situation before the new regulation [1] came into force in 2009.

Ultimately, only new measurement campaigns combined with statistical sound questionnaires can give complete and detailed answers on the outcome of the impact of the ecodesign regulations. However, these are expensive and time-consuming exercises and thus beyond the budget for many governments.

1.2 Selection of households

The selection has been done in cooperation with the Swedish statistics agency, “Statistics Sweden”. Households were chosen so there would be a good variety of possible combinations regarding different family types, building type (house or apartment), location (city, village, countryside) and construction date (old, recent, new). By the end of the measurement period, it was difficult to find households with the right criteria in the original sample set; therefore some additional households were recruited via personal contacts. It can be discussed whether this is all right from a statistical point of view, but the decision was made that more households were of use despite possible problems with bias etc. However this is the first measurement campaign ever for household electricity with the ambition to have a statistically correct representation of a nation

1.3 Geographical aspects

The geographic spread was limited to be within the region of Lake Mälaren, since it offered the desired variety of households within a practical distance. But since lighting use could probably vary as a function of latitude, a few households were chosen from the far north (Kiruna) and south (Malmö). Preliminary results, however, indicate no particular dependency of latitude.

1.4 Enquiries

The invited households were asked to fill in a detailed enquiry, with questions on the socio-economic background (address, age, gender, income, etc.), technical information on the dwelling (including their household heating system), and finally their appliances. Also, questions on the manufacturing model of white goods and TVs were also included. This information has been used in correlation analysis between stated energy performance (via the energy label for white goods) and actual energy performance [Bennich, 2009].

In addition, the electricians who installed the measuring equipment also filled in a detailed installation sheet which complemented and, in some cases, corrected the enquiries.

1.5 Measurements

The number of light sources in a typical Swedish home may be substantial; it can easily be over 60. Thus, measuring all of them was a difficult task and required a combination of direct and indirect measurements. It was performed in the following way, based on the concept used in the EURECO-study [Sidler, 2002]:

- Light sources were measured in an indirect way: light sensors measured when the lamps were on and off; together with information of the nominal power it was then possible to calculate the energy consumption (energy = power * time).
- The dimmable lamps were measured by serial meters placed between the socket outlet and the fixture.

Swedish homes usually have one fixed lighting outlet, usually in mid ceiling, and one over the kitchen sink. The rest of the fixtures are plugloads. In order to make the measurements cost-effective only 40 measurements have been carried out for a whole year. 349 have been measured for a month, evenly distributed over the year and then scaled up to annual values using a seasonality factor for each month that

[2] Regulation 1194/2012

[3] Regulation 874/2012

has been created from the yearly measurements. This has been done in order to correct for the considerable differences of daylight in summer and winter. See [Bennich, 2011]. All in all, measurements were performed in 200 houses and 189 apartments. The measurements started in September 2005 and ended June 2008. The measurements, most of the analysis and the reporting have been carried out by Enertech (French company) in collaboration with YIT (Swedish electric installer). Using the 10 minute data for lamp measurements, detailed load curves on a daily, weekly, monthly and yearly basis were achieved. In total there are more than 500 000 million data points for lighting.

1.6 The database

Due to the amount of data the appliances and the lighting database are separate. All data is stored in SQL format. Qlickview and Powerpivot were used as analysing tools. The database with the raw metering data is available for research purposes. Reports are available at the Swedish Energy Agency's homepage www.swedishenergyagency.se. Apart from the energy and time measurements, data on wattage and type of lamp (CFL, fluorescent, halogen 230 V, halogen low voltage and incandescent) was collected. The measurements were made on each fixture. There is also data on light sources per fixture and indoor temperature. Metadata includes type of rooms, areas in m^2, age of the building, age and sex of inhabitants, and household income.

1.7 Basis for calculations

From the main database one-person households were extracted, thus decreasing the total amount of dwellings analysed from 389 to 57. For each household, data on type of light source (CFL, fluorescent tubes, 230 V halogen, low voltage halogen and incandescent) combined with power and time in ON-mode per fixture were used for the calculations. The ON-mode time was divided with the total measurement time and then multiplied with the total hours of one year and the seasonality factor resulting in hours-ON per year. From these data the average energy demand per household can be calculated to 333 kWh/year.

2. Use of lighting

The measurements in the next tables and diagrams were made before the Ecodesign requirements came into force. Since the end of the 1990s very few, if any, CFL campaigns were carried out in Sweden and there was never a government subsidy. This could explain the low penetration of CFLs found in the study (Table 1). Fluorescent (tubular) light is used over kitchen sinks and in many flats attached to the kitchen ceiling.
Table 1 Average light sources in one-person households

Light sources	Light sources/household
CFL	2,2
Fluorescent - tubular	1,5
Halogen 230V	0,2
Halogen low V	1,0
Incandescent	10,5
Dimmable	0,5

Only data from 57 singles' households are presented, since it is only in this type of household the effects of occupancy control can be shown. One-person households are also becoming more and more common so they represent a significant part of all households.

Table 2. Use of existing light sources in one-person households.

Light source	Hours on/year
CFL	968
Fluorescent	725
Halogen 230V	219
Halogen low V	644
Incandescent	661

As CFLs and fluorescent light sources are more expensive than incandescent lamps, and have longer lifetimes, they are usually placed where light sources have to be on for longer times.

Regarding lighting, the annual energy consumed in a one-person household is 333 kWh. The analysis included only bathroom, bedroom, hall, kitchen and living room. If all rooms are included the sum is 373 kWh. The reason for not including other rooms, such as a second bedroom, office etc. is that these rooms do not occur in every household. As a comparison a two-person household consumption is 673 kWh/year and a 3+ household is 1068 kWh/year.

It can also be observed that the spread is considerable, see Figure 1.

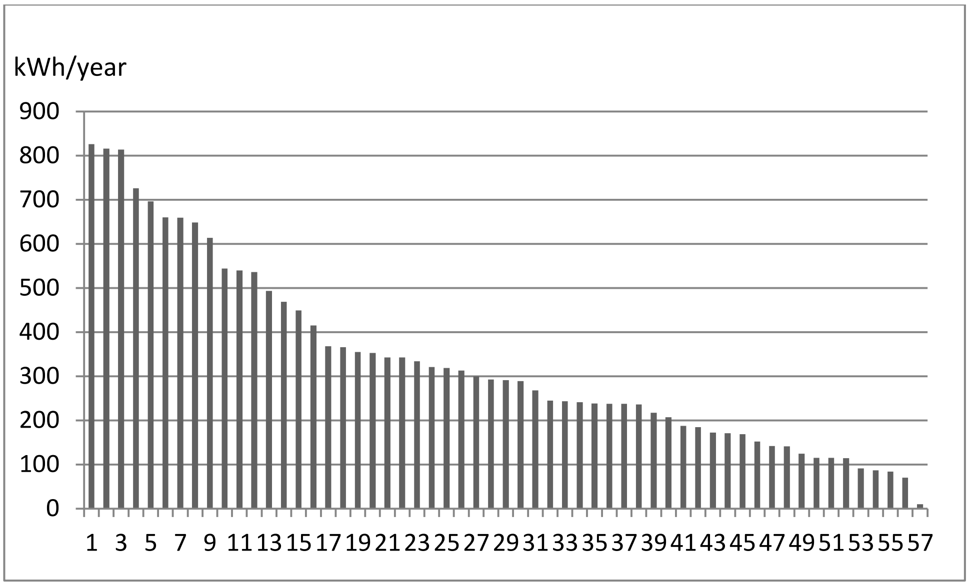

Figure 1. Annual energy consumption for the considered one-person households. Seasonality factor has been accounted for.

The household consuming less lighting energy related (far right in the diagram), 11,3 kWh/year, was measured during May and June, a time of the year when daylight is present even during the evening. Measurements during this period can give a too low total annual consumption even when correcting for seasonal effects (using the seasonality factor; see Section “Measurements” above for further explanations). However it was a three-room apartment in the middle of Sweden. The apartment was used every day, it had 8 CFLs and one fluorescent tube. Lamps were only used in one room at a time.

3. Change from incandescent to CFL/LED

The aim of this study is to quantify efficiency possibilities for lighting. This section deals with replacement of light sources. The first step is replacing incandescent light bulbs to the more efficient CFL or LED light sources. Since the annual hours-on and power for each light source is known, incandescent lamp’s retrofit analysis can easily be made. Averages are then calculated for all fixtures and then divided with the number of households. The result is divided with the base case, 330 kWh/year giving the percentages in Figure 2. The same procedure is then used for halogen lamps replaced by LEDs.

This study assumes that when changing from incandescent to CFL or LED the power is reduced by 80%, and that all incandescent light bulbs are changed to CFL or LEDs. However, recent Swedish market data[4] suggest that the replacement in many cases have been halogen 230 V class C. But if stage 6 in the lighting regulation 244/2009 (non-directional lighting) is fulfilled in 2016, halogen class C will be phased out[5]. Thus, the replacement will then be directed to LED, CFL and halogen 230 V class B, leading to a closer realisation of the theoretical savings.

The figure below show the percentage of electricity use when 1) all incandescent lamps are replaced and 2) when both incandescent and halogen lamps are replaced.

[4] The Swedish Lighting Association, private communication
[5] A possible abolishment of stage 6 is under current review by the Commission, and a decision is expected to be made under the fall in 2013.

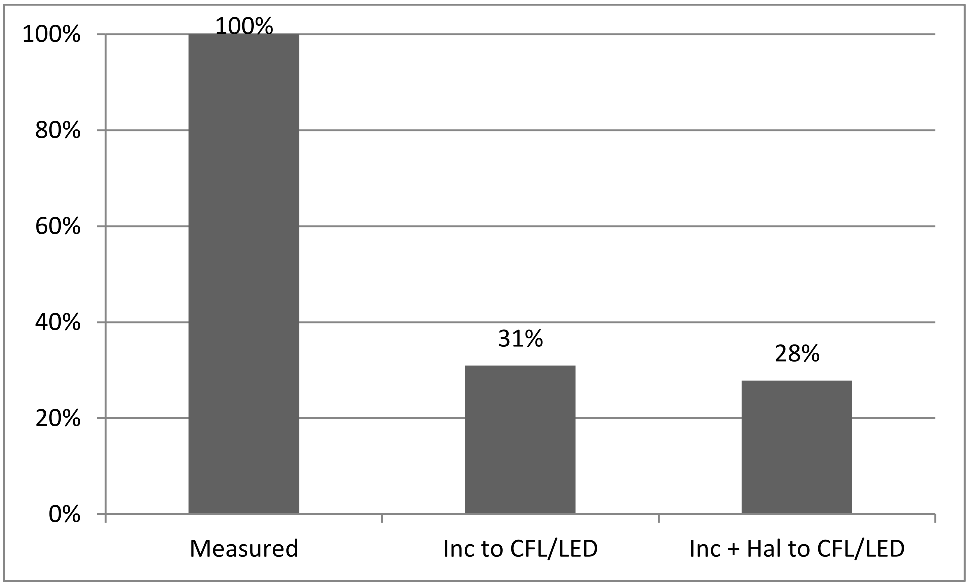

Figure 2. Replacement savings. Reduction of the average households energy demand when incandescent and halogen lightsources are replaced with CFL and LED. One person households

If all households had only incandescent lighting from the beginning the percentage for incandescent to CFL/LED in Figure 2 would be 20%. However, taking into account the existing CFL:s and . fluorescent light sources in the household and their usage, hours on, the remaining energy consumption will be 31%.

In a second step directional halogen lamps are replaced with LEDs. The resulting consumption with both measures applied will be 28%. One explanation for the limited decrease of halogen lamp's consumption is the low ownership of these types of light sources at the time of the measurements, see Table 1.

4. Occupancy and Circadian rhythms

In the foregoing section, savings due to simple replacements were addressed. In this chapter time-of-use will be explored, in two ways.

First, assuming a perfect control system, it would in principle be possible to use light only in the room where there is a person present; all other light sources in the other rooms should then be turned off. Since the normal case is that several rooms are lit all the time or at least a major part of the time, it is interesting to assess the relative savings if only one room is lit at any moment.

Secondly, recent insights of the relation between light and health suggest that we are not optimising the use of light from a health perspective. Depending on latitude and season, this can mean both under- and overexposure to light over the day, especially considering the light spectrum and time of the day. In Nordic countries it is normally assumed that people are underexposed to daylight, meaning that artificial light can be used to compensate for that in e.g. the evening. But care has to be taken of the light spectrum; as has been shown in recent years, a dose of blue light in the morning is a key component for entraining of the circadian rhythm. And opposite, a too strong exposure of not only blue light but light in general (flux levels should not be too high) in the evening could disrupt the onset of sleep and should therefore be avoided [Rea, 2013].

So, there are reasons to believe that artificial light is not used in an optimal way from a health perspective, and that there is a possibility to combine a both more healthy and efficient lighting by optimising the spectral distribution and total flux over the day. As a first estimate, based on discussions with Rea et al, it is assumed that the flux levels between 21.00 and 24.00 are actually too large with a factor of two. Thus, it is possible to assess what the savings will be if we adjust the flux levels to a more suitable level at the hours just before going to sleep.

So, assuming the perfect control system. Occupancy means how lights are lit in the apartment, for instance, whether all lights in all rooms are ON all the time, Figure 3, or only when the room is being occupied see Figure 4 and the discussion in section 2).

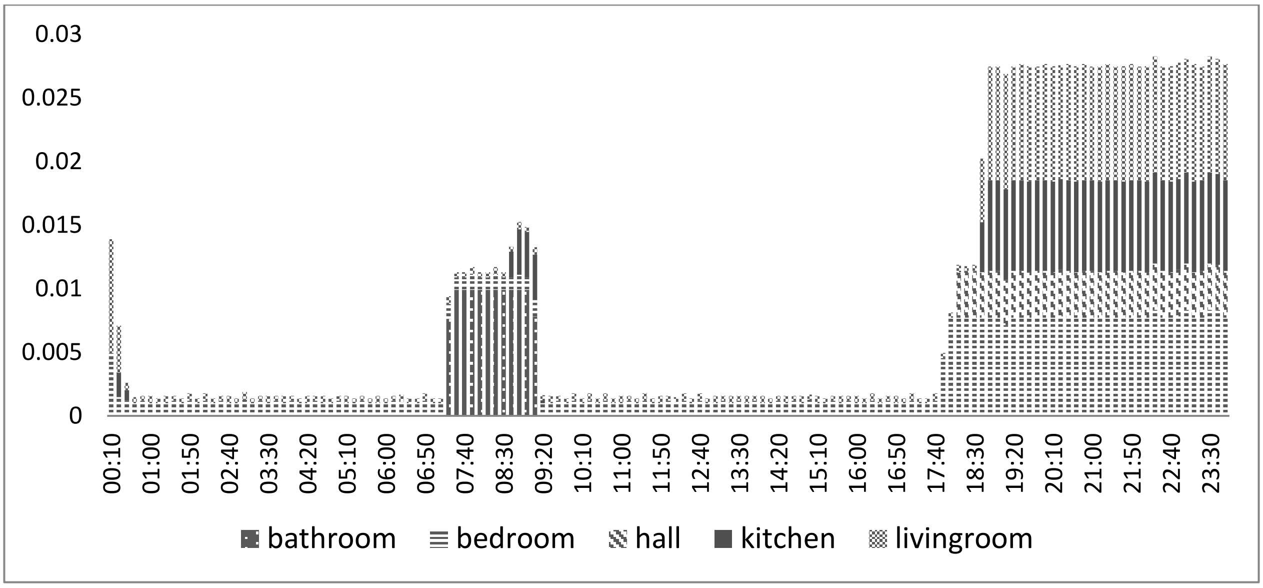

Figure 3. One-person household. Lighting energy consumption in kWh/10min. Example of having lights on in all rooms

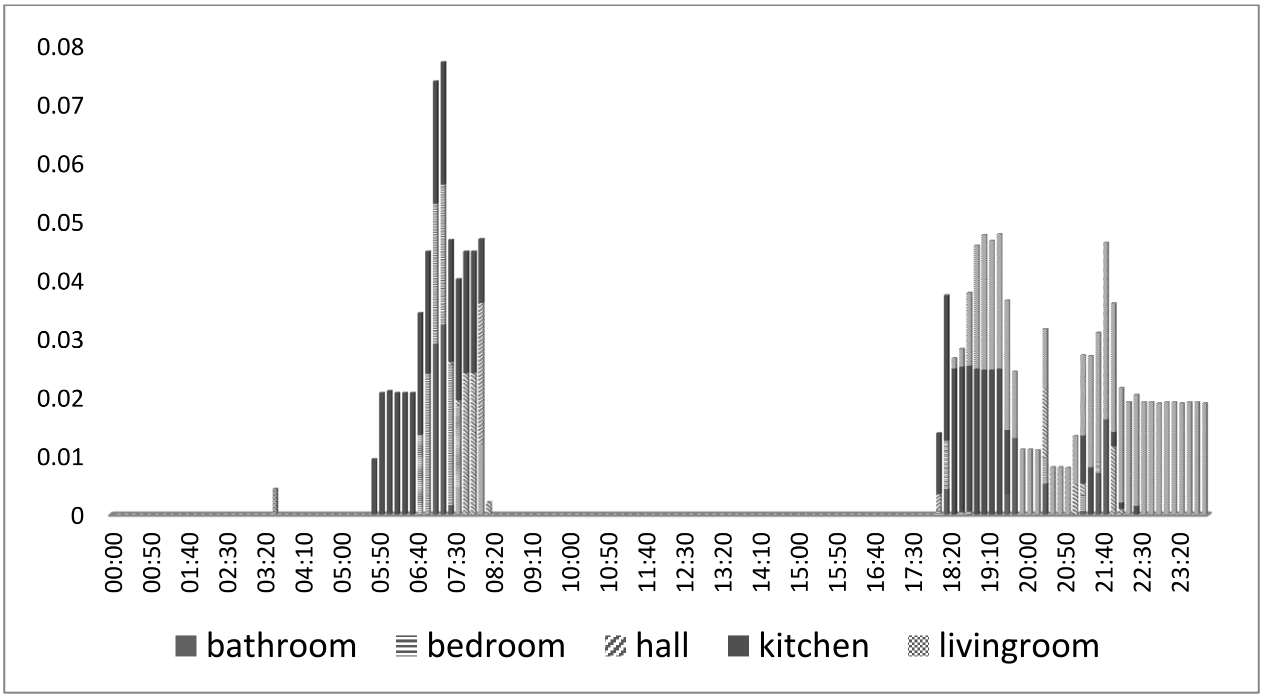

Figure 4. One-person household. Lighting energy consumption in kWh/10min. Example of using light in one room at a time in most of the evening

In order to find out the savings potential, lights in all rooms but one were turned off, for each dwelling in the database. The room which used most energy for lighting was left with the lights ON. Therefore, an underestimation of the possible savings is being made, as it was impossible to know which of the lit rooms, and at which time, was occupied, hence the conservative approach. One possibility could be to check if the TV, radio or oven was on, but other studies [Ofverholm, 2011] state that a TV or radio could be on 24/7. The demand for the room using most energy is divided with the actual energy demand for that specific household. The relative savings (in %) are presented in Figure 5.

How can these savings be achieved? Of course we can hope that everybody through information campaigns will learn how to treat the off button in each room like our grandmothers and grandfathers did. Taking into account the growing number of fixtures per household and the more affordable electricity information campaigns might not be enough considering the small amount of money that can be saved. For example the average yearly demand for one-person households in this study is 333kWh/year. Replacement of

incandescent with 333kWh times 28% gives 93 kWh. Reducing the time-on gives 93 kWh times 29%, (Figure 5), resulting in 27 kWh/year. In Sweden that would mean a cost of 27kWh*0,15 € = 4 € per year. The other way is through technology. In Sweden occupancy sensors are more and more common in offices and home control systems are emerging even though on a smaller scale. In addition occupancy and daylight sensors integrated into LED fixtures can be a very cost–effective solution.
However there is a psychological restraint, the fear of darkness. This could be overcome by dimming the lights to a low level in rooms not occupied. Dimmable CFL;s and LED;s exist on the market today but cost more.

Biological rhythms that repeat approximately every 24 hours are called circadian rhythms. Light is the main stimulus that helps the body's circadian clock, and thus circadian rhythms, maintain synchronization with the solar day. Humans need to be exposed to a sufficient amount of light of the right spectrum, for a sufficient amount of time, and at the right time, for our biological clocks to remain synchronized with the solar day. Otherwise, we may experience decrements in physiological functions, neurobehavioral performance, and sleep. No more than 100 lux at the cornea of a less circadian-effective white light source (i.e., less short wavelength energy), such as a 2700 Kelvin temperature (K) lamp, and minimizing any exposure to daylight, is recommended for evening hours. [Rea et al 2013]

The study does not allow to providing more specific recommendations as no lux measurements were done and since there was not enough data to calculate lux from lumens via the fixture performance and reflective surfaces of the room. In order to simulate the reduction in exposure for evening hours, light is halved between 21 and 24 o'clock. This could of course be done manually by shutting of some of the light sources in the room, but the preferable way is to do it with a home control system and dim the fixtures gradually. This will be called "flux regulation"; the resulting savings are presented in Figure 5.

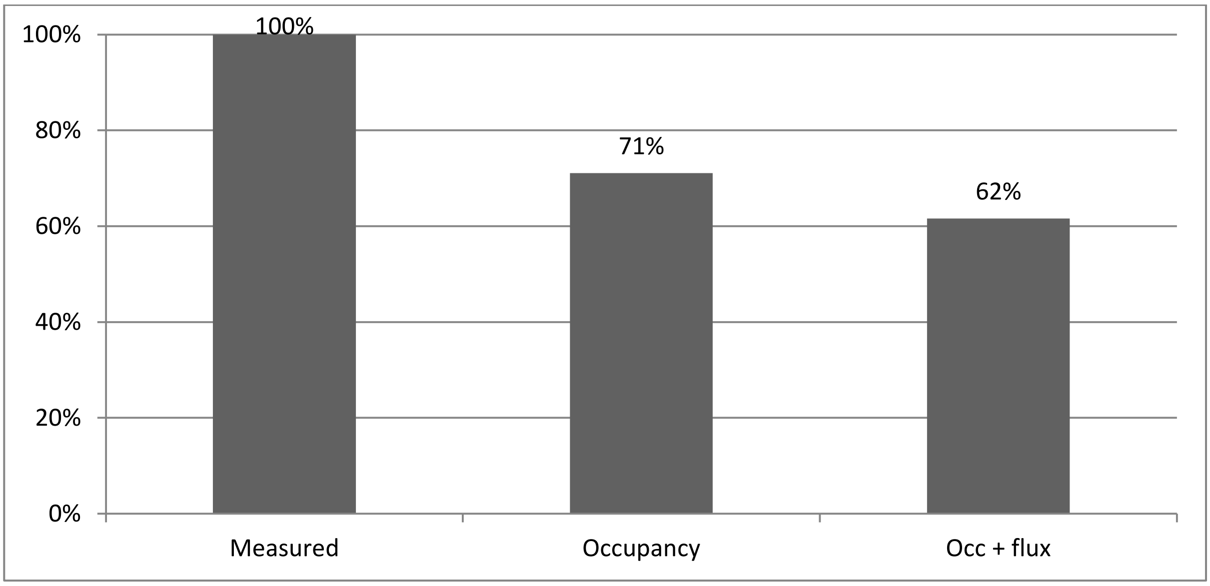

Figure 5. Time of use savings. Calculated average savings for one person households as percentage of energy demand. Measured, corresponds to 333kWh/year. Occupancy - only one room lit. Flux regulation - between 21 and 24 hours, half power.

5. Savings from applying all measures

In order to give an idea of all measures discussed above we can see from Figure 6 that for a one-person household the yearly energy reduction can be from 333 kWh to 59 kWh.

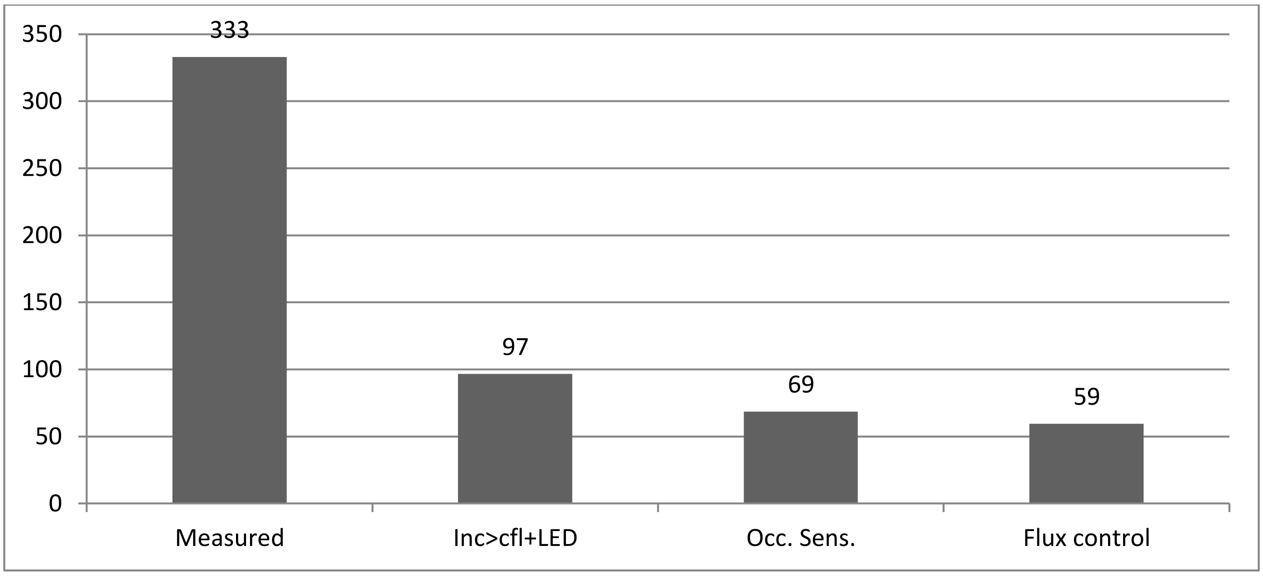

Figure 6 One-person household, kWh/year. Summary of the energy savings considering all measures analysed.

Figure 5 summarises the savings achieved by the measures analysed i.e. 1) when replacing incandescent lamps including halogens by CFL /LED, 2) adding occupancy sensors equivalent to switching of lights in rooms not occupied; 3) “flux control” represents reduced time–ON or dimming for lamps in order to meet demands on lower flux towards the end of the day.

6. Discussion

What are the chances that this will happen?

Regarding the type of light sources, a significant part of the changes has come true trough the ecodesign requirements. Unfortunately a considerable switch to halogen has occurred, but the entry into force of new ecodesign stages and the mandatory use of energy label, the halogen lamps will graduallly be replaced. For the rest of the measures – occupancy and lowering white lighting during the evening, common sense, availability and use of control systems and time should play its role.

The technology, type of products on the market and the use of LED is evolving at an amazing pace. There are good reasons to believe that LEDs will take over the market entirely as it is beginning to do in Japan[6] and the lm/W ratio continuous to follow the performance curve. Thus the energy saving calculations presented in this paper from replacing incandescent and halogen lamps may be too conservative.

A trend we have observed is that more fixtures are being installed per home, namely for creating lighting ambiences. This trend may reduce the potential for energy savings presented in this paper .

Occupancy sensors in other households than one-person’s, will probably have less impact than in this study, but still important especially combined with flux regulation.

Are our results representative for Sweden, Europe and in general? From a strict statistic point of view the results are probably not representative as the sample was not representative and we were not able to account all households that were measured. However, the measurement study provided, to our knowledge, the most detailed data that is available, wehich allow to produce very solid results,

[6] Japan is planning to produce only LED from 2020 and only have LED in the entire stock from 2030, according to a presentation by Mr Yoshihiro Kudo, NEDO, at the international workshop on Solid State Lighting, 8 March 2012, Tokyo.

A planning for a new study has just started. There is an increasing interest to study the impact of ecodesign and labelling activities. The final decision to go ahead will be taken by the end of 2013 or early 2014.

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Comparison of Omni-Directional LED Lamp Performance: How Do the IEA 4E Performance Tiers Compare to Current LED Lamp Technology in the United States?

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CLASP

Abstract

Lighting is responsible for 16% of the world's electricity consumption (Tsao & Waide, 2010). Solid state lighting (SSL) technologies have the potential to reduce lighting electricity consumption by 30% globally (IEA, 2012). To achieve this goal, SSL technologies, including light-emitting diode (LED) lamps, will need to achieve high levels of market adoption. This will only occur if these products meet consumer expectations of performance. To that end, the International Energy Agency's (IEA) Efficient Electrical End-Use Equipment (4E) program established an Annex focusing on addressing gaps and barriers to greater market penetration of LED Technology. As one of its three tasks, the SSL Annex focused on LED quality, and through that work established a series of performance tiers for a range of popular lighting products, including non-directional lamps. The IEA 4E SSL Annex performance tiers were developed as a tool for policy makers, who could use them as a framework for the development of performance standards and labels. Using data on the performance of 60W equivalent omni-directional LED lamps sold in the United States (US) in the last half of 2012, this paper assesses whether the IEA 4E SSL Annex performance tiers for omni-directional LED lamps for indoor residential applications are behind, ahead of, or in harmony with currently available LED technology.

The US LED performance data was obtained from recent testing conducted by the California Lighting Technology Center (CLTC) and funded by CLASP and the Pacific Gas and Electric Company (PG&E).[1] In 2012, the CLTC assessed the performance of omni-directional LED 60W equivalent lamps sold on the US market, focusing on several lighting characteristics known to be important to consumers – including efficacy,[2] color temperature, color rendering, and light output.

This paper provides valuable analysis to both IEA 4E members and US policy makers; IEA 4E members can use the analysis to inform future revisions to their performance tiers, while US policy makers can use it to inform the development of performance standards and labels for omni-directional LED lamps.

Key findings identified in this paper are summarized below:

- One lamp, out of the twelve different models of lamps assessed in this paper, meets the most stringent performance tier;
- Five lamps, out of the twelve different models of lamps assessed in this paper, failed to meet any performance tier, because they did not meet IEA 4E's requirements for luminous intensity distribution and/or light output;
- Four of the five lamps that failed to meet any performance tier did so because the lamps did not meet the IEA 4E SSL Annex performance requirements for omni-directionality. It should be noted that the manufacturers of these lamps claimed they were omni-directional; and,
- Three LED lamps, out of the twelve lamps assessed in this paper, had a color rendering index (CRI) value above 85, and one of these lamps had a CRI value above 90.

[1] The test report can be found on CLASP's website: www.clasponline.org/LEDTesting.

[2] Efficacy is measured in lumens per watt, and is a ratio of lamp's light output (in lumens) divided by the power consumed (in watts).

Key conclusions identified in this paper are:

- Based on the data, the IEA 4E's performance tiers align well with omni-directional LED lamps available on the US market;
- The Tier 3 level provides a good incentive for the continued improvement of omni-directional LED lamps;
- When a new methods for measuring light quality is developed by lighting organizations, IEA 4E SSL Annex members may want to consider adopting one or more of the new measurements; and,
- Policy makers may want to consider requirements on manufacturer claims of LED omni-directionality.

Background

Compact florescent lamps (CFLs), a more efficient lighting technology than traditional incandescent bulbs, have not reached significant levels of market penetration in the US and Europe. This is primarily due to several initial performance issues that consumers experienced when CFLs were first introduced. For example, some early CFLs made a humming noise, had poor color quality, and did not last as long as advertised. Although CFL performance has since improved, consumers remain biased against the technology due to these early experiences. As a result, CFLs have not achieved the level of energy savings they would have if the technology had achieved higher levels of market penetration.

New light emitting diode (LED) lamps, which are often more energy efficient than CFLs, are gaining popularity in the market for efficient lighting. Without appropriate performance requirements, however, LEDs are susceptible to similar performance issues to those encountered by consumers when CFLs first entered the market. Ultimately, addressing LED quality issues early will help to ensure that this new technology meets consumer expectations of performance, accelerating market penetration around the world, and thereby promoting considerable energy savings.

Sampling and Testing Methodology

The following section describes the sampling and testing methodology used by the CLTC to assess the performance of omni-directional LED lamps sold in the US.[3]

Sampling Methodology

The intent of CLASP and PG&E's testing was to assess the performance of LED main voltage (self-ballasted) replacement lamps equivalent to general service incandescent lamps. It is more challenging for manufacturers to produce a lamp that is equivalent to a 60W incandescent than an incandescent of a lower wattage. Consequently, CLASP and PG&E's testing assesses the performance of 60W-equivalent LED lamps. To select lamps that were most similar to general service incandescent lamps, CLTC developed the following selection criteria (California Lighting Technology Center, 2013):

- Shape: A19 or A21
- Luminous Flux: >600 lumens
- Correlated Color Temperature (CCT): 3000K or lower
- Light Distribution: Omni-directional

[3] For more information about the sampling and testing methodology, see the testing report on CLASP's website: www.clasponline.org/LEDTesting.

To identify LED lamps for testing, CLTC reviewed the US Department of Energy's (DOE) Lighting Facts Label database and identified 12 lamps fitting the selection criteria above. CLTC procured all 12 lamps from local or online retailers.[4]

CLASP and PG&E's testing does not identify manufacturers; thus, manufacturer's names, model numbers, and other identifying product information are not included in this paper. A description of each lamp tested is provided in Table 1 below.

Table 1 Omni-directional 60W-Equivalent LED Lamps Tested[5] [6]

Testing Serial No.	Voltage (V)	Luminous Flux (Lm)	Color Rendering Index	Correlated Color Temp. (K)	Rated Life (H)	Lamp Shape	Dimmable (Yes/No)	Beam Distribution
OMNI-01	120	800	Not Listed	3000	25000	A19	Yes	Omni Directional
OMNI-03	120	825	80	2700	25,000	A19	Yes	Omni Directional
OMNI-04	120	1100	Not Listed	2700	25000	A21	Yes	Omni Directional
OMNI-05	120	940	92	2700	25,000	A19	Yes	Omni Directional
OMNI-07	120	900	80	2700	25000	A19	Yes	Omni Directional
OMNI-09	120	800	82	3000	25000	A19	Yes	Omni Directional
OMNI-10	120	810	90	2700	25000	A19	Yes	Omni Directional
OMNI-11	120	800	Not Listed	3000	25,000	A19	Not Listed	Omni Directional
OMNI-13	120	810	80	2700	40000	A19	Yes	Omni Directional
OMNI-14	120	800	85	2700	50000	A19	Yes	Omni Directional
OMNI-16	120	810	94	2700	50000	A19	Yes	Omni Directional

[4] Due to budget and schedule constraints these lamps were not procured from different production batches; which should be taken into account when reviewing the results of our analysis.

[5] A total of 20 lamps were tested by CLASP and PG&E. Based on manufacturer self-reported claims, eight of these lamps were not omni-directional, and as a result they were not assessed in this paper. The Testing Serial Numbers in the paper are based on the testing serial numbers in the CLASP and PG&E testing report, thus some serials numbers are missing; e.g. OMNI-02.

[6] Descriptions are based on manufacturer self-reported data found on DOE's Lighting Facts database.

OMNI-20	120	1100	80	2700	25000	A19	Yes	Omni Directional

Source: (California Lighting Technology Center, 2013)

Testing Methodology

All lamps were tested to assess their performance across several lighting characteristics, including:

- Correlated color temperature (CCT);
- Color rendering index (CRI);
- Luminous flux (lumens); and,
- Power.

CLTC followed the Illuminating Engineering Society (IES) Approved Method: Electric and Photometric Measurements of Solid State Lighting Products (IES LM-79). The test samples were divided into three distinct testing groups:

- **Multiple Orientations Testing Group**: This testing was done in a two-meter integrating sphere according to IES LM-79. Two samples of each lamp listed in Table 1 were tested in the base up, base down, and base horizontal orientation. This testing compares lamps' baseline operating conditions in each of the three most common base orientations.

- **Lamp Consistency Testing Group**: This testing was done in a two-meter integrating sphere according to IES LM-79. Ten samples of each of the products listed in Table 2 were included in this testing group. Five of the samples are tested in the base up orientation, and five of the samples are tested in the base down orientation. The results of this testing allow for an analysis of the consistency of the baseline operating condition between multiple samples of the same product.

- **Light Distribution Testing Group**: This testing was done using a goniophotometer according to IES LM-79. One sample of each product from Table 1 was included in this testing group. The results of this testing provide light distribution data.

Photometric and electrical integrating sphere measurements were taken in a Labsphere two-meter integrating sphere. Photometric measurements were taken with an SMS-500 Spectrometer. Electrical measurements were taken with a California Instruments 751ix power analyzer. Photometric and electrical goniophotometer measurements were taken using a Type C Goniophotometer. Photometric measurements were taken with a T-10 Konica Minolta Illuminance meter. Electrical measurements were taken with a Xitron 2802 power analyzer. All of this equipment was selected to meet the photometric measurement requirements of IES LM-79. CLTC's laboratory had participated in and passed the National Institute of Standards and Technology's (NIST) Measurement Assurance Program (MAP) prior to testing.

Comparison of Tested Lamps Performance with IEA 4E Performance Tiers

IEA 4E SSL Annex has four performance tiers for non-directional (or omni-directional) SSL lamps: Tier 0, Tier 1, Tier 2, and Tier 3. This paper does not consider Tier 0, which only applies to off-grid applications. A summary of each performance tier is provided below:

- Tier 1 represents the minimum acceptable performance requirements for grid-connected applications.
- Tier 2 is similar in stringency to established voluntary performance requirements, such as those in the EU Quality Charter, the US ENERGY STAR program, or Japan's Green Procurement Law.

- Tier 3 is the most stringent performance requirement, and should capture the most advanced LED products in terms of efficiency and quality, such as products that qualify for the US DOE's L-Prize Award.

Each lamp was compared to the IEA 4E SSL Annex performance tiers. One lamp met the performance requirements for Tier 1. Four lamps met the performance requirement for Tier 2. Two lamps met the performance requirements for Tier 3. Five lamps failed to meet the requirements for any performance tier, because these lamps did not meet IEA 4E SSL Annex's requirement for luminous intensity distribution and/or light output. Table 2 below provides an overview of each lamp's performance.

Table 2: Summary of Tested LED Models' Characteristics Compared to IEA 4E Performance Tiers

Testing Serial No.	Light Output	Luminous Efficacy	Luminous Intensity Distribution	Color Rendering Index (CRI)	Correlated Color Temperature
Omni-01	Pass	T1	Pass	T2/3	T3
Omni-03	Pass	T2	Pass	T2/3	T1/2
Omni-04	Pass	T2	Pass	T2/3	T3
Omni-05	Pass	T3	Pass	T2/3	T3
Omni-07	Pass	T2	Pass	T2/3	T3
Omni-09	Pass	T1	Pass	T2/3	T1/2
Omni-10	Pass	T2	Fail	T2/3	T3
Omni-11	Pass	T2	Fail	T2/3	T3
Omni-13	Fail	T2	Fail	T2/3	T3
Omni-14	Fail	T1	Pass	T2/3	T1/2
Omni-16	Fail	T2	Fail	T2/3	T3
Omni-20	Pass	T2	Pass	T2/3	T3

The following sections summarize each lighting characteristic individually.

Light Output:

Light output is the total amount of light that an LED lamp emits. The minimum light output requires the total light output of the LED lamp to be at least equivalent to the light output from an incandescent lamp.

The corresponding minimal initial light output (lumens) for 60W equivalent, applying to all the samples in this study, is 800 lm. Figure 1 shows the light output of each tested lamp. Among the 12 omni-directional LED models, nine models passed the minimum light output for 60W equivalent while three failed.

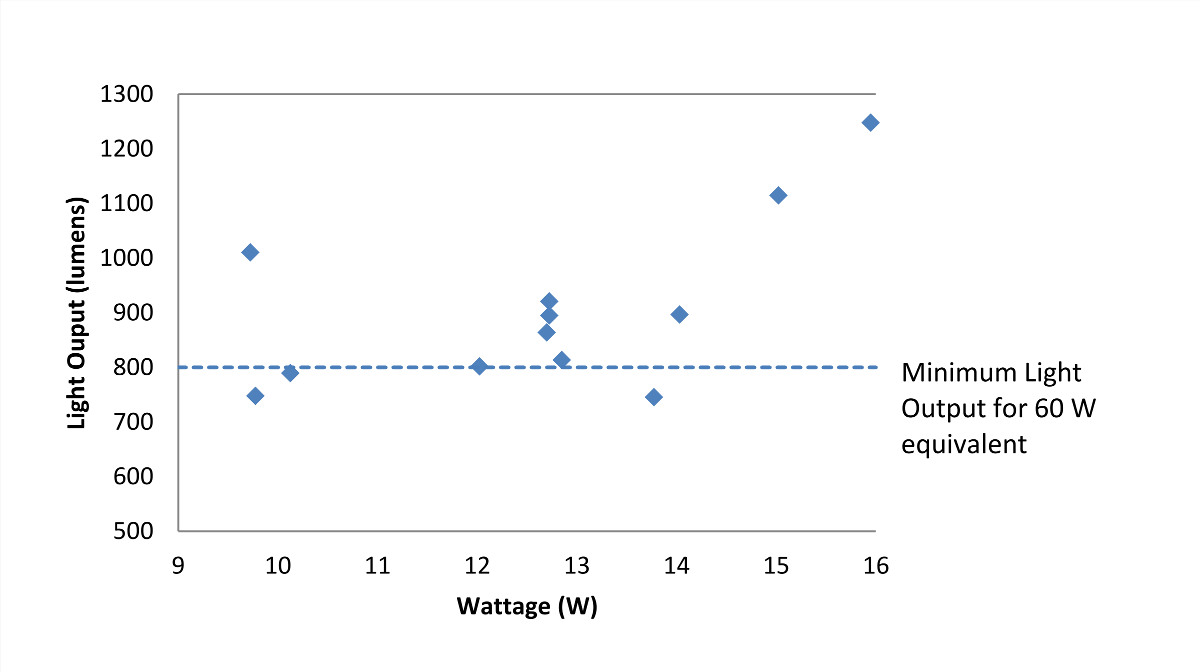

Figure 1 Average Light Output vs. Wattage of Tested LED Models
Source: (California Lighting Technology Center, 2013)

Luminous Efficacy:

Lighting products use luminous efficacy (lm/watt), the ratio of the total light output of a lamp compared to power consumed to evaluate energy efficiency. The higher the efficacy, the more efficient the lighting product is. The minimum lamp luminous efficacy is one the most important criteria to evaluate energy and cost saving potentials, because it ensures that LED lamps are saving the energy that manufacturers claim.

Figure 2 shows the average efficacy of each tested LED model, and performance tier levels. Among the 12 omni-directional LED models, eight are Tier 1 (>50 lm/W), 12 are Tier 2 (>65 lm/W), and one is Tier 3 (>80 lm/W).

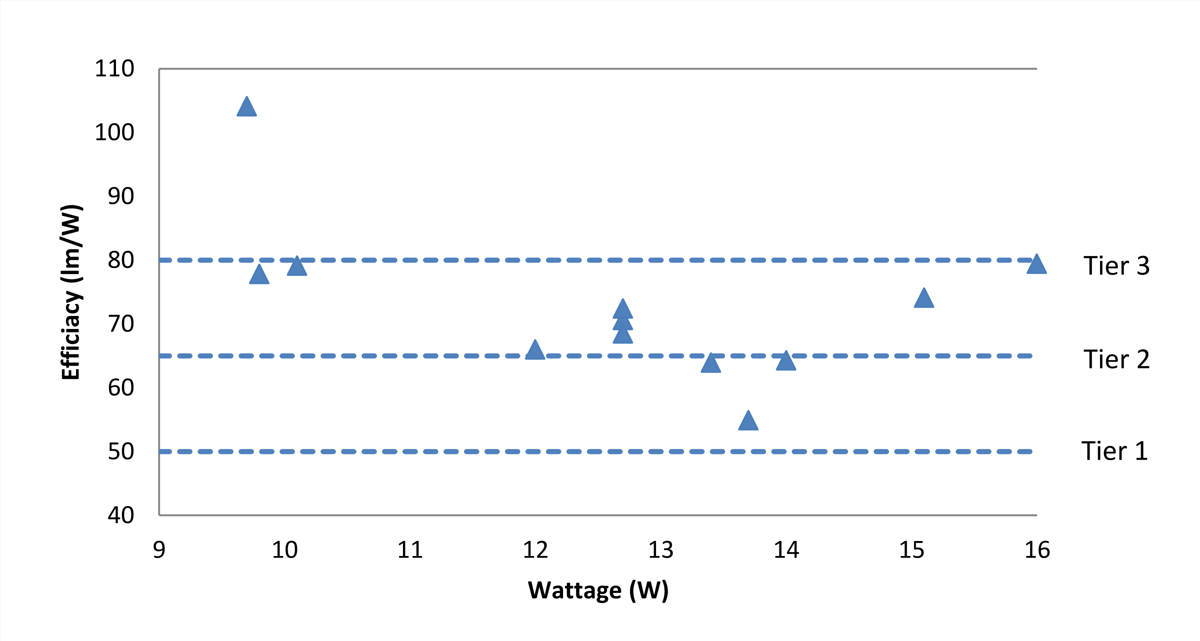

Figure 2 Average Luminous Efficacy vs. Wattage of Tested LED Models
Source: (California Lighting Technology Center, 2013)

Luminous Intensity Distribution:

Luminance intensity distribution is the measurement of the distribution of light, which can be used to determine if an LED lamp emits light uniformly. Omni-directional lamps will emit light spherically (in all directions). For most general incandescent lamps, this light is uniform. This is not always the case for LED lamps; because of their construction, some LED lamps have uneven light distribution. This can lead to performance issues. For example, LED lamps with uneven light distribution placed in light fixtures that have lamp shades may only illuminate the top portion of the lamp shade, leaving the rest of the lamp shade dark.

The IEA 4E SSL Annex developed a quality requirement for luminous intensity distribution in order to test for this performance characteristic.[7] Table 3 indicates which lamps meet IEA 4E SSL Annex's requirements for light distribution and which do not. All 12 lamps were reported as omni-directional by their manufacturers on the DOE Lighting Facts Label database. Of these 12 lamps, four lamps did not meet the IEA 4E's requirements for luminous intensity distribution.

Table 3: Summary of LED Models to the IEA 4E's Requirement for Luminous Intensity Distribution

Testing Serial No.	Omni-Directional Beam Pattern
OMNI-01	Pass
OMNI-03	Pass
OMNI-04	Pass
OMNI-05	Pass

[7] The IEA 4E SSL Annex requirement applies to lamps at Tiers 2 and 3 only, and it reads: "Products shall have an even distribution of luminous intensity within the 0° to 135° zone (symmetrical about the vertical axis). Luminous intensity at any angle within this zone shall not differ from the mean luminous intensity for the entire 0° to 135° zone by more than 20%. At least 5% of total flux must be emitted in the 135° - 180° zone. Distribution shall be vertically symmetric in three vertical planes, 0°, 45°, 90°."

OMNI-07	Pass
OMNI-09	Pass
OMNI-10	Fail
OMNI-11	Fail
OMNI-13	Fail
OMNI-14	Pass
OMNI-16	Fail
OMNI-20	Pass

Color Rendering Index (CRI):

The color rendering index (CRI) is a measurement of light quality. It measures how well the lamp renders eight unsaturated color samples relative to an incandescent reference source.

CRI is not a perfect measurement for white light LED lamps, because LED lamps do not radiate light evenly across the entire color spectrum. For example, an LED lamp may render the eight-color sample measurement for CRI well, but not render another color important to light quality. Consequently, the LED lamp could have a high CRI score but not meet consumer expectations of color quality.

Several researchers are investing better methods for measuring LED light quality. For example, the National Institute of Standards and Technology (NIST) have developed an alternative metric called the color quality scale (CQS); it is currently under consideration in the International Commission on Illumination (CIE). Until a better metric is adopted, CRI should be viewed as one measure of LED light quality, not as a definitive measurement.

Figure 3 shows the average efficacy of each tested LED model, and performance tier levels. All twelve omni-directional LED models tested are in the Tier 2 and Tier 3 level.

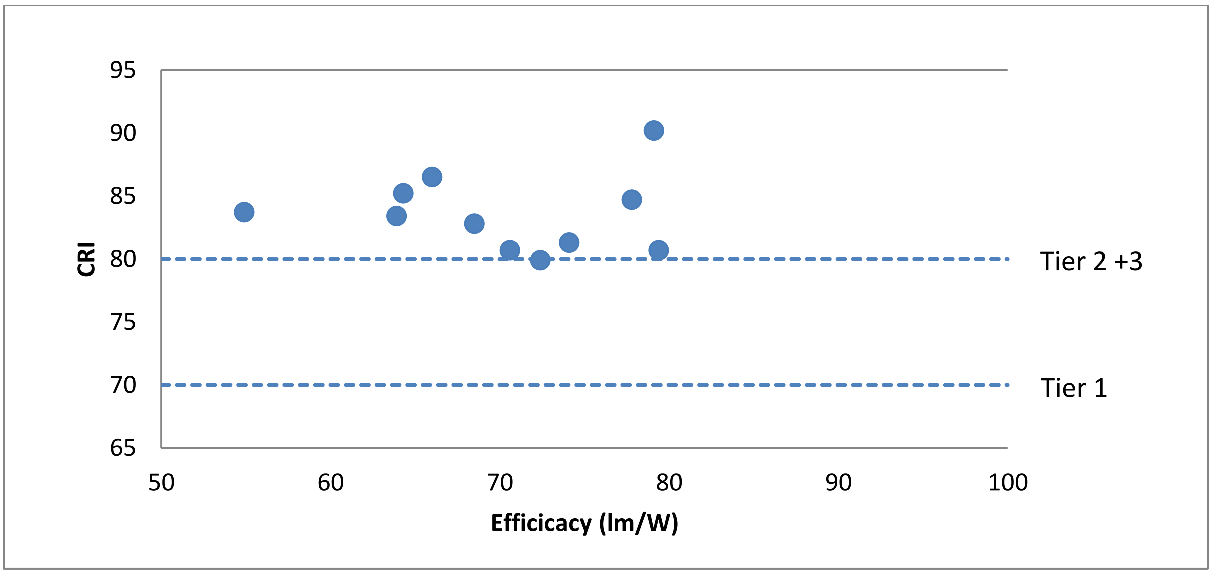

Figure 3 Average CRI vs. Efficacy of Tested LED Models
Source: (California Lighting Technology Center, 2013)

Correlated Color Temperature:

Correlated color temperature (CCT) measures the warmth or coolness of the light produced by a lamp in Kelvins (K). Consumers in the US and Europe generally prefer a warmer light (2,700K to 3,000K). IEA 4E SSL Annex does not require a particular CCT, but instead defines a maximum tolerance around a claimed CCT value by a manufacturer. So, for example, if a manufacturer claims their lamp is 27000K, then it must be measured at 2725K +/- 145 K or it would be considered mislabeled. These tolerance ranges were set by ANSI C78.377 and adopted by the Annex. The results of our comparison are shown in
Table 3 below.

Table 3 IEA 4E Performance Tiers for Correlated Color Temperature Target and Tolerance

	Tier 1	**Tier 2**	**Tier 3**
Correlated Color Temperature Target (K) and Tolerance	Follow ANSI C78.377, excluding flexible CCT 2700K (2725±145) 3000K (3045±145) 3500K (3465±245) 4000K (3985±275) 5000K (5028±283) 5700K (5665±355) 6500K (6530±510)	Follow ANSI C78.377, excluding flexible CCT 2700K (2725±145) 3000K (3045±145) 3500K (3465±245) 4000K (3985±275) 5000K (5028±283) 5700K (5665±355) 6500K (6530±510)	Follow ANSI C78.377-2011 Table 6A, for 4-step quadrangle excluding flexible CCT 2700K (2723±82) 3000K (2940±98) 3500K (3397±125) 4000K (4036±154) 5000K (4991±220) 5700K (5665±270) 6500K (6432±340)

Source: (IEA, 2012)

Table 4 displays the assessment of each model's CCT performance tier. The first column lists the LED model number; the second column lists the tested CCT for each LED model, the third and fourth columns show the color temperature target for Tiers 1, 2, and 3. The last column is the performance tier for each LED model based on the criteria in
Table 3.

Table 4 Correlated Color Temperature (CCT) of Tested LED Models and Corresponding Performance Tiers

LED Model	**Measured CCT (in K)**	**CCT (in K)**	**Corresponding Tier**
Omni-01	3032	3000	T3
Omni-03	2639	2700	T1/2
Omni-04	2677	2700	T3
Omni-05	2733	2700	T3
Omni-07	2858	3000	T3
Omni-09	3054	3000	T1/2
Omni-10	2648	2700	T3
Omni-11	2943	3000	T3
Omni-13	3022	3000	T3
Omni-14	2624	2700	T1/2
Omni-16	2777	2700	T3
Omni-20	2714	2700	T3

Source: (California Lighting Technology Center, 2013) and (IEA, 2012)

Conclusion

Several conclusions can be drawn from comparing the performance of omni-directional 60W-equivalent LED lamps currently sold in the US to the IEA 4E SSL Annex performance tiers. These are as follows:

- Only one lamp (Omni-5) meets the luminous efficacy requirement set for Tier 3. This lamp significantly surpassed the requirement with an efficacy above 100 lumens per watt. Balancing efficacy with lower CCT and high CRI is challenging for manufacturers. With only one lamp meeting Tier 3 requirements, it appears that the Tier 3 level is a good target for the continued improvement of omni-directional LED lamps.

- All of the lamps meet the CRI requirement for Tier 2 and 3. Three of the lamps were significantly higher with CRI scores above 85; one of these lamps (Omni-5) had a CRI above 90. The IEA 4E SSL Annex performance requirements for Tier 2 and 3 are both set at 80 CRI. With three lamps at or above 85 CRI, it is possible that the Tier 3 requirement could be set at a higher CRI. However, as described above, a lamp that scores high in CRI does not necessarily have better light quality than a lamp with lower CRI. When a new a new method for measuring light quality is developed, IEA 4E SSL Annex members may want to consider adopting the new measurement.

- All of the lamps assessed in this paper were listed as omni-directional on DOE’s Lighting Facts database. Testing found that four of these lamps did not meet the IEA 4E SSL Annex’s requirements for omni-directionality, even though the manufacturers of these lamps listed them as omni-directional. Policy makers may want to consider requirements on manufacturer claims of omni-directionality.

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LEDs and Solid-State Lighting: the potential health issues

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Abstract

Solid-state lighting (SSL) is expected to become the most widely used type of light source, promising to bring significant energy savings as it replaces older technologies. However, due to specific spectral characteristics of white light emitting diodes (LEDs), as compared to other artificial sources, some concerns have been raised regarding safety. SSL products should be proven to be at least as safe as the products they intend to replace, and new or unusual conditions of usage should be considered.

This paper deals with potential health issues related to LED lighting, with a focus on light flickering and the "blue light hazard". An overview is given on current studies and latest expert opinions on photobiological safety. Following our measurements, the risk groups of a few consumer LED lamps are determined. We also make recommendations on how to limit the risk through regulation at the EU level. In addition, we have studied the flickering of fifty LED lamps, which were found to have widely varying behaviour (ranging from zero to one hundred per cent flickering). This last result is rather embarrassing because light flicker may cause temporary illness and visual fatigue. It is rather clear that the potential impacts of LED products on human health and well being has to be taken into account seriously before low quality and potentially harmful products submerge the European market.

Introduction

Solid-state lighting (SSL) is currently revolutionizing the field of lighting and its practices. In the long term, inorganic and organic light emitting diodes (LEDs) will become the most widely used light sources. White LEDs have shown a steady growth of their luminous efficacy for more than fifteen years; promising to bring significant energy savings as they replace older lighting technologies. However, as any new or emerging technology, SSL products should be proven to be at least as safe as the products they intend to replace. Also, in new lighting applications where older technologies could not be employed, the safety of SSL products should be assessed considering new or unusual conditions of usage.

The potential risks posed by SSL to the human health can be classified into the three following categories:

- potential risks due to the emitted optical radiations: interactions of the optical radiations with the skin and the eye (photobiological safety), undesired effects of optical radiations on vision (glare and flickering effects in particular);
- effects of optical radiations on circadian rhythms;
- electrical safety;
- and potentials risks due to exposure to electromagnetic fields.

The first two points are due to the specific spectral characteristics of white LEDs as compared to other artificial light sources. This paper focuses on these issues, and more especially on the blue light hazard and flickering. A paper section is devoted to each one of those points. Experimental results obtained at both LAPLACE[1] and CSTB[2] are used to support the discussion.

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Photobiological hazards

Photobiological hazards are related to the effects of optical radiation on the skin and the eye. The interactions of radiation with biologic systems occur through absorption, with the radiant energy being transferred to the biological tissues. Two main mechanisms can be distinguished [1]:

- heat related, where radiant energy is converted into molecular movement (kinetic energy) such as vibration, rotation and translation;
- photochemistry, where radiant energy causes excitation of atoms or molecules, displacing the outermost valence electrons to higher orbital energy levels. This energy can subsequently be utilized in (photo-)chemical reactions yielding ‘photoproducts’.

Two key features of LEDs have attracted the attention of lighting specialists, ophthalmologists and photobiologists:

- most LEDs are small sources emitting very bright visible light;
- the vast majority of commercial LEDs producing white light rely on a chip emitting blue light associated with layers of phosphors to produce longer wavelengths by fluorescence. As a consequence, the emission spectrum of a white LED consists in a narrow blue primary peak and a large secondary peak in the yellow-orange-red region. These two peaks are separated by a region of very low emission in the blue-green part of the spectrum. Such typical white light LED spectrum is illustrated on Figure 1.

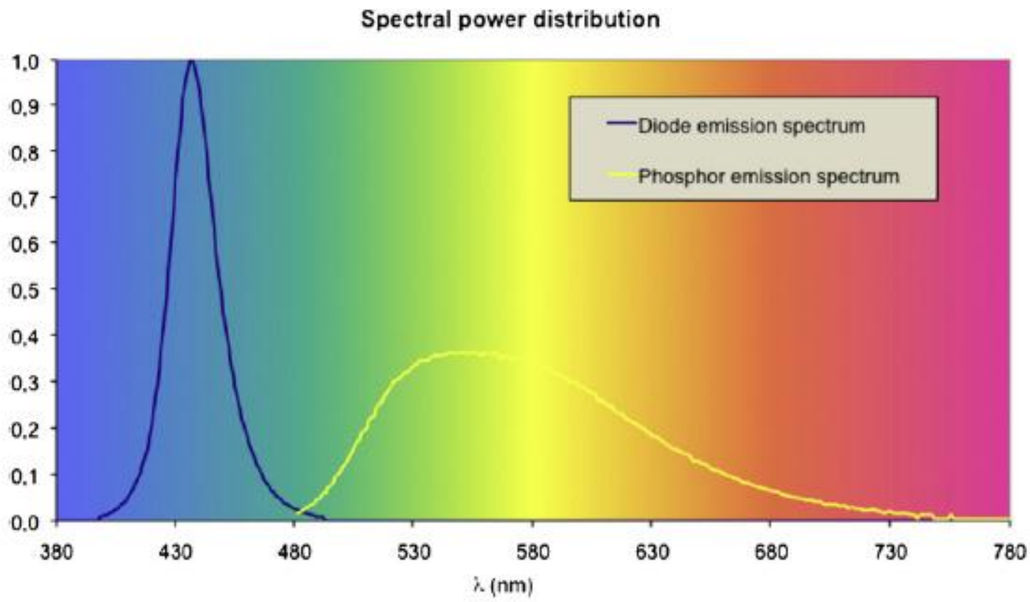

Figure 1: The two components of a typical white high-brightness LED spectrum.

Note that LEDs currently used in SSL emit negligible amounts of ultraviolet and infrared radiations, hence only visible light related effects are under scrutiny.

Radiation hazards for the human eye

The exposure levels needed to produce thermal damage on the retina cannot be met with light emitted by LEDs of current technologies. As far as the eye is concerned, adverse photochemical effects of light are summarized in Figure 2.

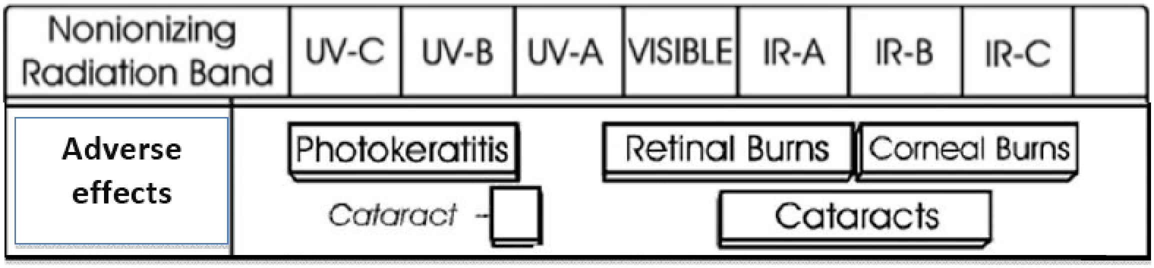

Figure 2: Adverse photochemical effects on the eye tissues as a function of wavelength [2]

In general, photochemical damages on the retina depend on the accumulated dose to which the subject was exposed (*i.e.* short exposure of high intensity or low intensity over longer periods).

The only effect of acute exposure to UV, particularly UVB and UVC below 300 nm, is photokeratitis of the cornea and conjunctiva. The accepted threshold levels for photokeratitis is 3-4 mJ/cm^2 at 270 nm and 10 mJ/cm^2 at 300 nm. Infrared radiation may be responsible for cataracts; the accepted threshold is in the order of 4 W/cm^2 for wavelengths higher than 800 nm [2]. As LEDs used in lighting applications emit negligible amounts of UV and IR, it should not be expected to contribute to the apparition of photokeratitises and cataracts. However, chronic effects of exposure to LED light are unknown. It should be noted that chronic UV exposure from sunlight might cause corneal lesions (climatic droplet keratopathy), as well as cortical and nuclear cataracts of the lens.

As far as other wavelengths are concerned, visible light is focused on the retina by the cornea and the crystalline lens. The amount of light falling on the retina is directly proportional to the radiance of the light source. Due to the high brightness of LEDs, the retinal illuminance levels are potentially high and must be carefully considered. For this reason, it is important to consider the potential retinal toxicity of LEDs.

Radiations in the blue end of the spectrum have long been known to provoke photochemical retinal injuries [3]. The underlying physiological mechanism causes important injuries for exposures over ten seconds. Symptoms include permanent scotoma (or "blind spot"), and there is a strongly suspected link with age-related macular degeneration (AMD) [4]. Light-induced retinal degeneration is known to involve complex series of events such as apoptosis (cellular death), inflammatory response, and free radicals, but the full understanding of the phenomenon is still an active research field in ophthalmology.

Retinal blue light exposure can be estimated using the ICNIRP[3] guidelines [5]. A quantity called the blue-light weighted radiance L_B can be obtained as a function of the viewing distance and the exposure time. It can be calculated as follows:

$$L_B(\vec{x},\vartheta) = \int_{300nm}^{700nm} L(\vec{x},\vartheta,\lambda)B(\lambda)d\lambda$$

Where L($\vec{x}$, ϑ, λ) is the spectral radiance at wavelength λ at a position $\vec{x}$ on a surface in a direction defined by angle ϑ to the normal of the surface and B(λ) is the Blue Light Hazard sensibility function given in Figure 3.

[3] International Commission for Non-Ionising Radiation Protection

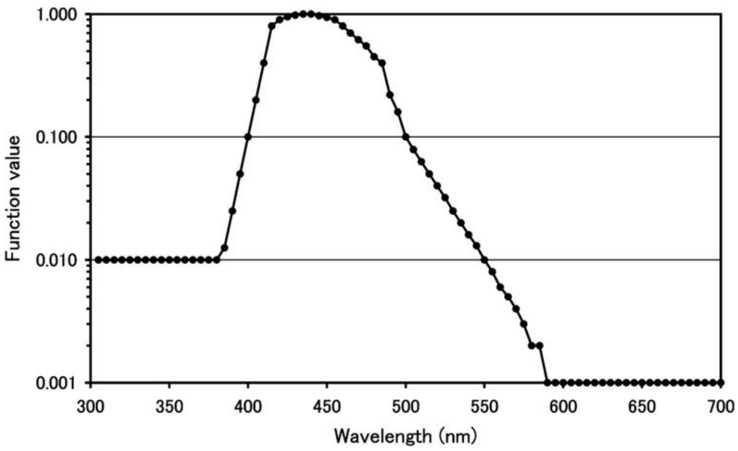

Figure 3: Blue light hazard function as given by [6]

Maximum permissible exposure values (MPEs) were set by ICNIRP to provide limits for L_B as a function of exposure time [17,18]. These limits are dependent on the exposure time. In addition L_B is not intended to be measured for infinitesimal solid angle and surface, but averaged over a finite field of view called the "effective field of view" (FOV). The FOV is precisely defined by the ICNIRP guidelines. It increases with the exposure time in order to account for the spreading of the image of the light source on the retina with the micro-movements of the eye.

For all LEDs and products using LEDs, a photobiological blue light hazard assessment must be carried out to determine whether or not the MPEs can be exceeded in the conditions of usage. The main tool to perform photobiological risk assessment is the CIE S009 publication whose content was transposed in an international standard (IEC 62471) and other national standards (IESNA RP27, JIS C8159, etc.).

Based on IEC 62471, lamps and lamp systems are classified into risk groups for various photobiological hazards. The risk group depends on the maximum permissible exposure time (MPE time) assessed at a given viewing distance:

- Exempt Group (RG0: no risk): MPE not exceeded within 10^4 s;
- Risk Group 1 (RG1: low risk): MPE not exceeded within 10^2 s;
- Risk Group 2 (RG2: moderate risk): MPE not exceeded within $2{,}5 \times 10^{-1}$ s (eye blink time)
- Risk Group 3 (RG3: high risk): MPE exceeded even for momentary or brief exposure (less than $2{,}5 \times 10^{-1}$ s).

For the past few years, blue light exposure data have been provided by LED manufacturers, professional lighting associations, independent laboratories, and governmental agencies. It was found that the retinal blue light exposure levels L_B produced at a distance of 200 mm from the user by blue and cold-white LEDs (bare LEDs and LEDs equipped with a focusing lens) exceed the MPEs limits set by ICNIRP after an exposure time comprised between a few seconds for high power blue LEDs to a few tens of seconds for high power cold-white LEDs. Figure 4 shows L_B for the six blue LEDs chosen by the ANSES working group [7] and published in [8]. In this example, the LEDs were operated such that they emitted a radiant flux of 0,5W, which is about half the rated maximum value.

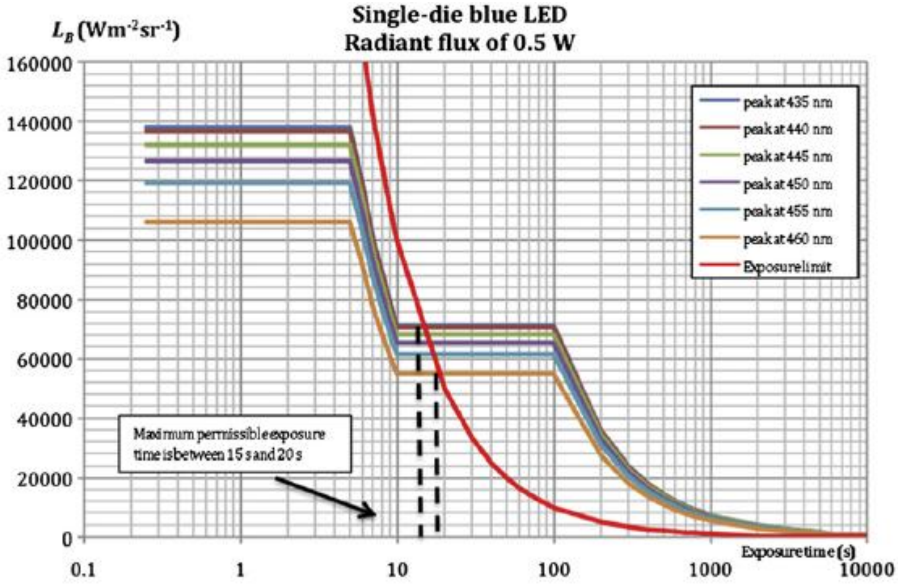

Figure 4: Variation of L_B with the exposure time determined for six types of blue LEDs (measured by CSTB). The red curve is the exposure limit value. The intersect point corresponds to the maximum permissible exposure time. It can be used to determine the risk group [8]

These L_B curves exhibit a first plateau corresponding to a uniform luminance when the FOV is smaller than the light source. When the FOV is greater than the size of the effective light source, the luminance L_B decreases following a 1/t law. The second plateau corresponds to a constant FOV, when the exposure time is comprised between 10 s and 100 s. After 100 s, the FOV increases again and the luminance L_B decreases again as 1/t. In this example, the maximum permissible exposure times of these LEDs are between 15 s and 20 s. These values correspond to the Risk Group 2 (moderate risk).

For this study, we used various single LEDs under conditions of constant luminous flux. When cold-white LEDs were operated such as to provide a luminous flux of 100 lm, the exposure limit value was never reached and the risk group was always 0 (no risk). By increasing the luminous flux to 200 lm, all the cold-white LEDs fell into risk group 2 (moderate risk) with maximum permissible exposure times comprised between 40s and 100s. Similarly, neutral-white LEDs operated at a luminous flux of 100 lm all fell in risk group 0. When operated at 200 lm, the exposure limit value was reached at an exposure time of about 100 s, thus the studied products fell into the risk group 1 (low risk). Warm-white LEDs never exceeded the exposure limit value and were always in risk group 0 (no risk), even when they were operated at a flux of 200 lm. In fact these warm-white LEDs should reach a luminous flux of at least 500 lm to belong to risk group 1 (low risk). Table 1 recapitulates these results.

Table 1: Risk groups and maximum exposure times for various LED lamps as measured by CSTB

LED type	Luminous flux (lm)	Risk Group		Max exposure time (s)
Cold White	100	RG0	No Risk	-
	200	RG2	Moderate Risk	40s-100s
Neutral White	100	RG0	No Risk	-
	200	RG1	Low risk	100 s
Warm White	100	RG0	No Risk	-
	200	RG0	No Risk	-
	500	RG1	Low risk	100 s

None of the studied single-die LEDs presented a high risk (risk group 3). Blue LEDs and cold-white LEDs may belong to risk group 2, according to their colour temperature and their operating point. Likewise, neutral-white LEDs may belong to risk group 1. On the contrary, all warm-white LEDs belonged to risk group 0.

Several classes of products and applications based on bare LEDs or LEDs covered by a focusing lens (collimator) could result in high levels of retinal blue light exposure when viewed from a short distance. Such conditions may occur because:

- of testing and adjustments of high power blue and cold white LEDs by operators in lighting manufacturing facilities or by lighting installers;
- bright cold white LED lamps in the visual field of children;
- automotive LED daytime running lights when activated near children and other sensitive people.
- LED lamps sold for home applications (consumer market) in which case lamps can be viewed at distances as short as 200 mm.

The photobiological safety of a final SSL product (lamp, luminaire, etc.) must be assessed independently of its LED components. As a matter of fact, the L_B value of an SSL product is generally very different from the L_B value of the LED components that it uses. For instance, a higher L_B can be obtained for a luminaire using an assembly of low L_B LEDs. On the opposite, a lower L_B can be obtained for a luminaire using a diffuser in front of a high L_B LED.

The IEC 62471 standard defines two different criteria to determine the viewing distance. Light sources used for general lighting service should be assessed at the distance corresponding to an illuminance of 500 lx. Other types of light sources should be assessed at a fixed distance of 200 mm.

For LED components, there is no ambiguity in the distance since LED components are not used very often in general lighting. In this case, IEC 62471 requires using the distance of 200 mm. The application of the IEC 62471 measurement technique at 200 mm leads to a classification in risk group 2 (moderate risk) for some high power blue and cold white LEDs.

However, the choice of the viewing distance in IEC 62471 is sometimes ambiguous and not realistic in the context of the real usage conditions. For instance, let us mention stage lighting (*i.e.* theatres and concert halls) where artists are exposed to illuminance levels higher than 500 lx. Applying the 500 lx criterion would underestimate the exposure while the 200 mm criterion would largely overestimate it. In a more common context, directional household lamps fall under the 500 lx criterion, which corresponds to a typical viewing distance of a few meters. It is however quite common to have shorter viewing distances, as short as 200 or 500 mm at home. Another example is street lighting where the illuminance level is much lower than 500 lx, typically a few tens of lx. Assessing the blue light hazard associated of a street lighting luminaire by using the 500 lx illuminance distance is clearly inappropriate.

It is interesting to note that the strict application of CIE S009 and IEC 62471 to indoor LED lamps and luminaires lead to RG 0 and RG 1 classifications, similar to traditional indoor light sources (fluorescent lamps, incandescent and halogen lamps). Nevertheless, several measurement campaigns using the 200 mm viewing distance revealed that some indoor LED lamps and luminaires belong to RG2 while traditional indoor light sources (fluorescent and incandescent) remain in RG0 or RG1. This result shows that LED technology potentially increases the blue light hazard in home applications where the viewing distance is not limited, notably when light sources are accessible to children and other sensitive people. At the time of this writing, the general public is not aware of the potential since no mandatory labelling system exists for SSL products.

As a consequence, the potential toxicity of some LED components viewed at short distances cannot be neglected. When the viewing distance is increased to one meter, the maximum permissible exposure time rapidly increases to a few thousands of seconds, up to a few tens of thousands of seconds. These rather long exposure times provide a reasonable safety margin to assert than there is virtually no possible blue light retinal damage from LEDs at reasonably large viewing distances (statement valid for state of the art LEDs at the time of writing).

However, lamp installers and users awareness on the notion of a safety distance should be raised. The safety distance of a SSL product would be the minimum distance for which the blue light hazard risk group does not exceed RG1.

For SSL products aimed at consumer applications (retrofit LED lamps, for instance), the policy makers in collaboration with health authorities advocate the adoption of a regulation to limit the risk group to RG1 at the minimum viewing distance encountered at home, which is 200 mm. Equivalently a mandatory safety distance less than or equal to 200 mm should be required. The measurement campaigns carried out by several laboratories showed that the vast majority of indoor LED lamps and luminaires already comply with this requirement. It is not a critical issue for the LED industry

Other widely used lighting sources, particularly high intensity discharge lamps (metal-halide lamps for instance), are also in RG2. However, this last example is intended for clearly identified usages and can only be installed by professionals presumably aware of the safety distance required to limit the exposure.

In addition, the maximum exposure limits defined by the ICNIRP and used to define the Risk Groups in both IEC 62471 and CIE S009 are not appropriate for repeated exposures to blue light as they were calculated for a maximum exposure of one 8-hours day but do not take into account lifetime exposure effects. Moreover, neither CIE S009 nor IEC 62471 account for specific light sensitivities, such as:

- individuals having pre-existing eye condition for which artificial lighting can trigger or aggravate pathological symptoms;
- aphakics (*i.e.* absence of crystalline lens) and pseudophakics (*i.e.* artificial crystalline lenses) persons, who consequently either cannot or insufficiently filter short wavelengths (particularly blue light);
- children, as their visual system is not mature;
- and elderly people, as their skin and eyes are more sensitive to optical radiation

The case of the skin

As far as interactions with the skin are concerned, the general population should not be concerned by risks arising from the use of LEDs in lighting.

Thermal effects from visible or IR radiation emitted by lighting sources are unlikely to cause any serious health effects in healthy skin; problems may only arise with excessively intense sources and close proximity with such sources (adherence to DIN 33403 for pain thresholds [9] or more conservative expansion of the ICNIRP limit to exposure times over 10 s). Considering the data on UV effects, the sunburn reaction would appear to be the practical key for proper control of UV exposure levels on the skin, both for short- and long-term health effects. In contrast to persons deliberately exposing themselves to sunbeds for cosmetic or presumed health effects, persons staying indoors do not expect to be exposed to UV radiation from the artificial lighting system, and LEDs should therefore evidently be adequately low in UV output.

Only a small number of people suffering from photosensitive syndromes might see an aggravation of their pre-existing condition triggered by exposure to LEDs emitted blue light. Patients taking photosensitizing drugs should also be aware of a potential risk.

Light Flickering hazards

Flicker is the modulation of the light output that can be induced by fluctuations of the mains voltage supply, residual ripples in the DC current powering, or deliberate modulations of the LED input current such as the pulse-width modulation (PWM) used for dimming applications.

It is known that exposure to light flicker (in particular at frequencies between 3 Hz and 55 Hz) can cause photosensitive epileptic seizures in various forms, depending on the individual and his visual pathology, the contrast, the wavelength and the viewing angle or distance [10].

According to the literature, light flicker is not usually perceptible at frequencies higher than 70 Hz, but it can still affect people. For example, people suffering from migraines are more likely to be sensitive to flicker at high frequencies [11]. Also, for people suffering from specific medical conditions, flicker may have some serious consequences.

Light flicker combined to rotating motion or spatial patterns may be responsible for stroboscopic effects. Stroboscopic effects might induce hazards to workers in proximity to rotating machines and tools.

On the opposite, pulsed lights may also have some positive effects: it has been reported that the pulsed operation of lamps could offer opportunities for energy savings according to the Broca-Sulzer effect [12, 13] due to enhanced perceived brightness. Thus, it is argued that energy savings can be achieved by using pulsed LEDs at very high frequency. In that case it is absolutely necessary to understand the influence of flicker on humans in order to avoid any deleterious effects appearing with products using that type of pulsed light.

In this section, we present original results that prove that some readily available consumer SSL products have very high flicker behaviour and can potentially be harmful for the end-user.

Commercially available LED lamps may have serious light flickering behaviour at twice the mains frequency (in Europe mains frequency is 50 Hz thus the observed residual flicker frequency is equal to 100 Hz). This light flicker is mainly due to the residual voltage fluctuation after the AC/DC rectifier in the lamp power supply. For this paper, we developed an experimental method to quantify flicker and then evaluate the behaviour of various commercially available products.

Definition and Experimental evaluation of flickering

There are two widely accepted metrics for measuring lamp flicker. Figure 5 is used to illustrate these two metrics.

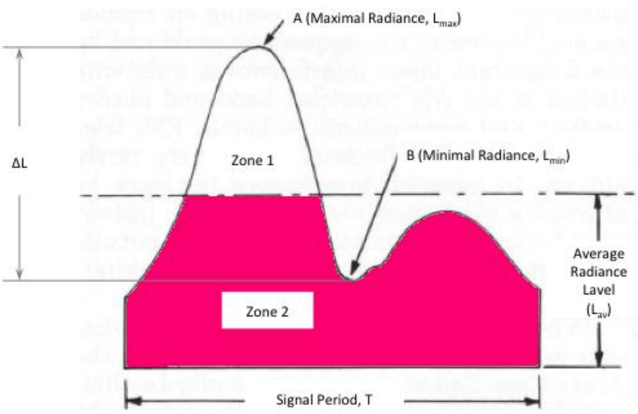

Figure 5: Definition of light flickering metrics [16]

The first, called the per cent flicker, uses the maximum and minimum points of the fluctuation levels through the following equation:

$$t_L(\%) = 100 \frac{\Delta L}{L_{av}}$$

The second metric is the flicker index and requires the calculation of the areas above and below the average level of the signal [14].

$$FI = \frac{Surface\ zone\ 1}{(Surface\ zone\ 1) + (Surface\ zone\ 2)}$$

For the moment, no regulation of light flicker is implemented in the EU regulations. In the USA, the present Energy Star specifications for lamps set maximum Flicker Index values for flicker frequency of 120 Hz or higher. Draft 4 of Energy Star requirements released in late April 2013 requires that all marketed lamps should have a maximum flicker index at those frequencies and above. It defines a maximal flicker index requirement for dimmable lamps and under any dimming condition as follows:

$$FI \leq 0{,}001 \times \text{ flicker frequency in Hz}$$

The above formula defined an increase of the threshold with frequency in order to account for situations that might occur with pulse-width modulation supply.

This criterion leads to FI<1,2 for USA and FI<1,0 for Europe. The rational used by the US Environmental Protection Agency (EPA) to establish that limit appears to originate from experiments on high-quality conventional light sources, including CFLs, performed by the US Department of Energy (DoE). In this work, the highest FI value is 0,11 for magnetically ballasted CFLs. There is also a statement suggesting a value of 0,15 for magnetically ballasted fluorescent lamps. In addition, the IES lighting handbook [16] presents a maximum flicker index value of 0,20 related to ballasted High Pressure Sodium lamps. A number of LED manufacturers are asking for a higher limit value, but none of their arguments are based on factual data. The 0,12 value might be fixed in the next months.

In order to evaluate the light flickering magnitude, a specific experimental set-up was designed in the LAPLACE laboratory. It is described in Figure 6. The set-up is based on an integrating sphere equipped with a selenium cell and a Tektronix 2002B oscilloscope for detecting and recording the light waveforms. A digital multi-metre is used to independently measure the average light output, directly proportional to the luminous flux of the lamp. All lamps were operated at 230 V, 50 Hz (mains) via a controlled voltage power supply. More than fifty different lamps of different brands have been tested with this device.

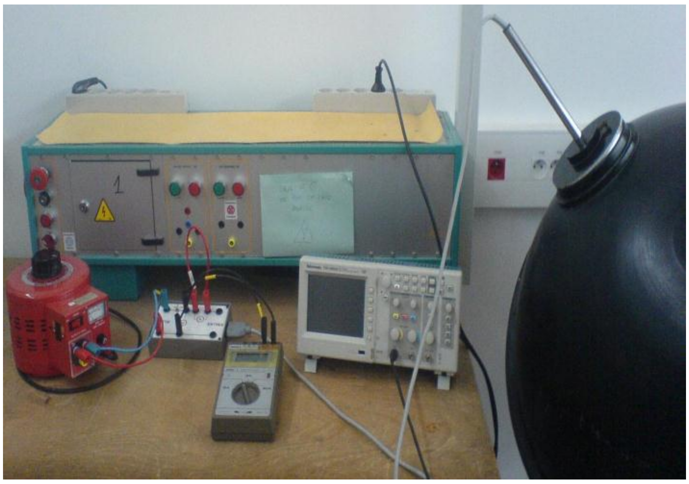

Figure 6: Diagram of the flicker measuring set up in LAPLACE

In our evaluation, the per cent flicker, as defined above, is used. However, as shown in Figure 7, we demonstrated experimentally that for periodic waveforms, there is an almost linear relationship between per cent flicker and flicker index.

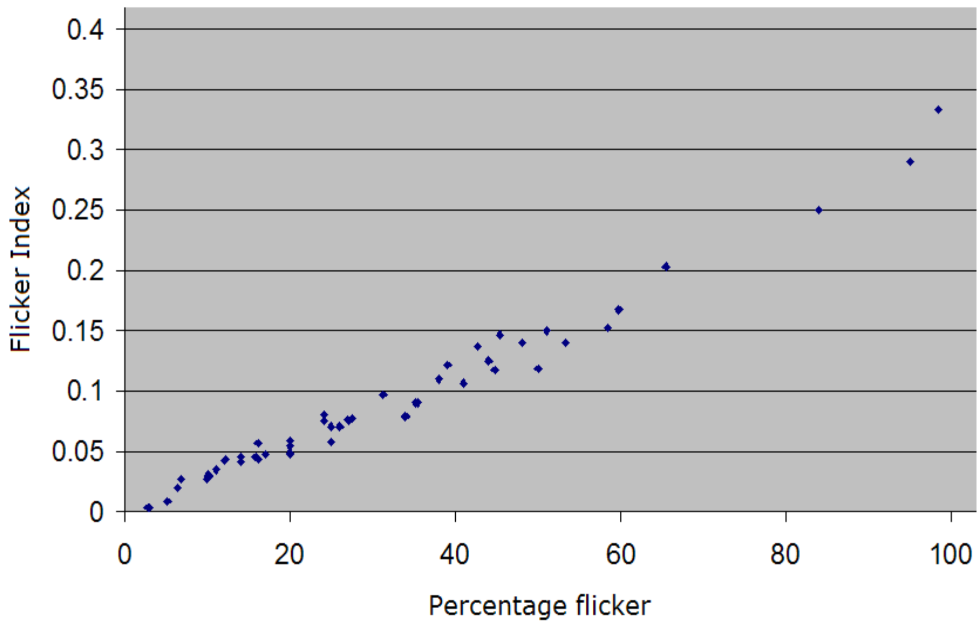

Figure 7: Correlation between flicker percentage and flicker index as measured in LAPLACE laboratory

Our set of test lamps included LEDs, as well as CFLs and incandescent lamps used as references. Figure 8 shows the experimental per cent flicker values for some tested lamps. It should be noted that a 100 W incandescent lamp has a flicker percentage of 10% due to the filament temperature variation that follows the power waveform. Good quality CFLs may reach a per cent flicker of 20%. The highest Flicker Index value for tested CFL lamps was found to be 0,14, a value rather compatible with the EPA requirements.

#	Fabricant	Type	Technologie	tL (%)
1	[illegible]	[illegible]	GLS	14,30
2	[illegible]	[illegible]	GLS	3,47
3	[illegible]	[illegible]	GLS	10,30
4	[illegible]	[illegible]	CFL	7,00
5	[illegible]	[illegible]	CFL	11,00
6	[illegible]	[illegible]	CFL	14,20
7	[illegible]	[illegible]	CFL	8,88
8	[illegible]	[illegible]	CFL	9,90
9	[illegible]	[illegible]	CFL	9,60
10	[illegible]	[illegible]	LED	36,10
11	[illegible]	[illegible]	LED	6,70
12	[illegible]	[illegible]	LED	0,00
13	[illegible]	[illegible]	LED	0,00
14	[illegible]	[illegible]	LED	0,00
15	[illegible]	[illegible]	LED	100,00
16	[illegible]	[illegible]	LED	0,00
17	[illegible]	[illegible]	LED	86,40
18	[illegible]	[illegible]	LED	8,37
19	[illegible]		LED	24,50
20	[illegible]		LED	17,60
21	[illegible]		LED	0,00
22	[illegible]		LED	0,00
23	[illegible]		LED	0,00
24	[illegible]		LED	0,00
25	[illegible]	[illegible]	LED	85,70
26	[illegible]	[illegible]	LED	0,00
27	[illegible]	[illegible]	LED	0,00
28	[illegible]	[illegible]	LED	93,20

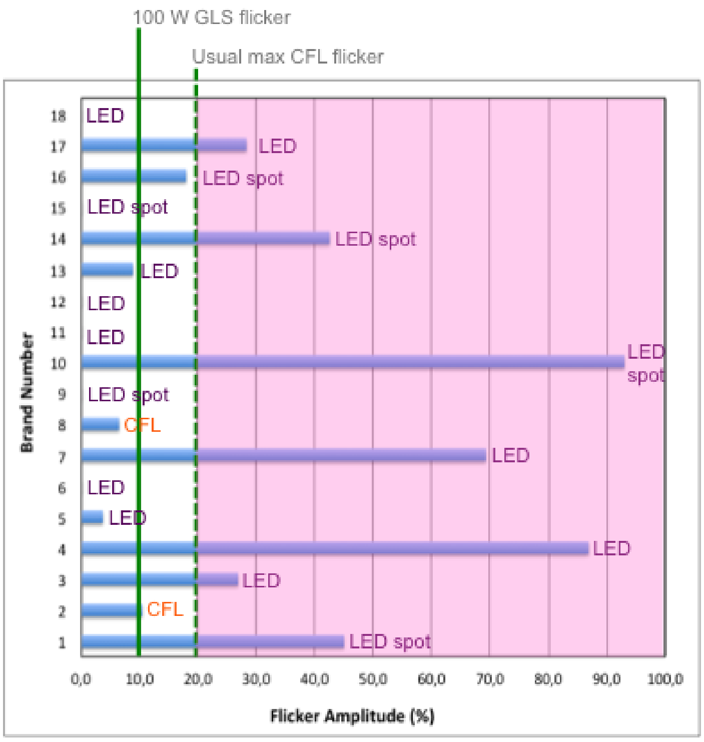

Figure 8: Some experimental percentage flicker values of various lamp technologies as obtained in LAPLACE laboratory and EU-PremiumLight projects

The situation is completely different for LEDs. As can be seen in Figure 8, LEDs had completely arbitrary behaviours. Some of them feature high quality power supplies that include reliable AC/DC rectifiers and filters. They displayed very low flicker, close to zero (not measurable). Other devices had per cent flicker values up to 100%. In this case, the light output goes off every 10ms. Eight LED lamps were found to fully respect the conditions imposed by the Energy Star requirements (Flickering Index < 0,1), whereas all examined CFLs fulfilled that condition.

It should be noticed that Kitsinelis et all [15] proposed a very effective way to detect light flickering using the camera of a cellular phone. Figure 9 shows the obtained results by this method. The simplicity of the method allows its use by the general consumer: just use a smart phone with an integrated camera, target the lamp and look at the phone screen. If striations appear around the lamp (dark fringes), then flicker is present. The contrast between the fringes is a straightforward estimation of the "flicker depth". The spatial frequency of the fringes is related to the flicker frequency and the frame rate of the camera.

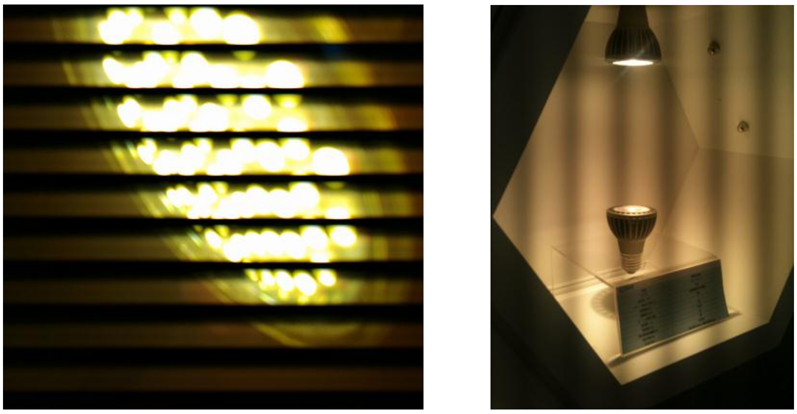

Figure 9: Flicker detection using the built-in camera of a cellular phone obtained by LAPLACE. Flicker is leading to the appearance of dark fringes in the image.

Conclusions

Solid-state lighting (SSL) and more especially light-emitting diodes (LEDs) are presented as the next generation of light sources that may amount to 70-80% of the light source market by 2020. LEDs will unquestionably help making energy savings in both indoor (residential and tertiary) and outdoor lighting sectors. However, recent work showed that this technology might have some impact on human health.

This paper addressed potential health issues related to LEDs and based on original experimental data. More especially, we focused on the photobiological effects of blue light and light flickering phenomena.

Concerning the blue-light hazard, and more particularly in consumer applications (retrofit LED lamps for instance), we strongly support the adoption of a regulation to limit the risk group to RG1 at the minimum viewing distance encountered at home, which is 200 mm. The measurement campaigns carried out by the authors, as well as by several other independent laboratories, showed that most indoor LED lamps and luminaires already comply with this requirement. It is not a critical issue for the LED industry. However, the notion of a safety distance would actually be more appropriate to communicate to the installers and to the users, especially to the general public. The safety distance of an LED based product would be the minimum distance for which the blue light hazard risk group does not exceed RG1 and this value must be indicated on the package. For LED products handled exclusively by professionals, all necessary measures to limit the final risk group to RG1 have to be taken and guaranteed by the installers.

In addition, none of the single-die LEDs studied in the present work fell in high risk group (RG 3), corresponding to a maximum permissible exposure time of less than 0,25 s. Blue LEDs and cold-white LEDs according to their colour temperature and their brightness may belong at maximum to risk group 2, especially if beam collimators are used. Likewise, neutral-white LEDs may belong to risk group 1. On the contrary, warm-white LEDs studied here all belonged to risk group 0.

Concerning light flicker, we tested more than fifty different lamps for flickering. Our samples included LED lamps as well as some CFLs and incandescent lamps as benchmarks. The highest Flicker Index value for tested CFL lamps was found to be of 0,14. LED lamps had completely arbitrary behaviour. Some of them, built with high quality power supply, displayed zero flicker (not measurable) while some other devices reached per cent flicker values of up to 100%. In fact only eight LED lamps have been found to fully respect the Energy Star requirement (Flicker Index < 0.1), while all the tested CFLs fulfilled that condition. Consumer should be vigilant about that fact. In this paper, we described a rapid method to detect flicker using a smart phone camera.

There is no clear requirement concerning light flicker limitation in Europe, which is clearly unacceptable. On the opposite, the value of FI<0,12 was proposed in the USA by the EPA in their last draft of Energy Star requirements. The requirement seems to be very stringent and is said to threaten some innovations such as the ac-LED technology. A limit value of about 0,25 may be more realistic at least for applications in which light flicker is not a critical issue.

All in all, the European Union must rapidly engage in a systematic and cross-disciplinary research effort to better understand and quantify potential health effects, and ultimately enforce a consistent regulation protecting end-users while promoting innovation in the growing SSL market.

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Product Classification for LEDs: Lessons Learned from Other Emerging Technology Efficiency Policies

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Abstract

When an emerging energy efficient technology enters the market, policymakers decide on standards and labels (S&L) for the new technology. Regulations dealing with emerging technologies can either treat the new technology as a large-scale substitute for existing technologies, or as a competitor among products with similar functions but with fundamentally different characteristics. Decisions on product classification and standards levels directly impact how manufacturers innovate, the range of consumer choices and, ultimately, the extent to which the full potential or energy savings are achieved.

S&L policymakers may want to look to past examples in developing regulations for light-emitting diodes (LEDs), a fast growing emerging technology with potential to save up to 42% of total lighting energy worldwide by 2020. Since 2007, at least twenty national, regional, and international specifications have been launched to regulate the quality and performance of LEDs. These specifications are not consistent due in part to lack of consensus regarding whether to categorize LEDs as a new product class regulated separately from existing technologies or as an addition to the general lighting category that is a competitor among products with similar functions.

To decide which regulatory path to take, this paper studies analogous rulemaking processes in the European Union, United States, and Australia for three products that were once considered emerging technologies: heat-pump water heaters, compact fluorescent lamps, and high intensity discharge lamps. Based on these case studies, this paper identifies advantages and disadvantages of possible regulatory paths for addressing LED product classification and global implications.

Introduction

When an emerging technology enters the market with the promise of reduced energy consumption, energy efficient standards and labeling (S&L) policymakers typically are challenged to decide on the utility value of, and policy for, the new technology. This is because regulations dealing with emerging technologies typically can take either of two paths: treating the new technology as a technical innovation that is a large-scale substitute for existing technologies, or as a competitor among products with similar functions but with fundamentally different characteristics. Those decisions on product classification strongly influence the extent to which the full potential for energy savings can be achieved and also affect market structure and the range of consumer choices.

S&L policymakers may want to look to past examples in developing regulations for light-emitting diodes (LEDs), a fast growing emerging technology that has a potential to save up to 42% of total energy in the lighting sector worldwide by 2020 [16]. Over the past five years, at least twenty national, regional, and international specifications have been launched to regulate the quality and performance of LEDs [1]. However, these specifications are not regulated in a consistent way due to the lack of consensus in S&L policy regarding whether to categorize LEDs as a new product class that is a substitute for existing technologies or as an addition to the general lighting category that is a competitor among products with similar functions. Consistent policies have the potential to foster global energy savings sooner.

To decide which regulatory path to take, this paper studies analogous rulemaking processes in the European Union, United States, and Australia for three domestic appliances and lighting products that were once considered emerging technologies when they entered the market: heat-pump water heaters (HPWHs), compact fluorescent lamps (CFLs), and high intensity discharge lamps (HIDs). Based on analysis from these case studies, this paper identifies advantages and disadvantages of possible regulatory paths to take for addressing LED product classification issues so as to facilitate and accelerate the rulemaking process for LEDs around the world.

How other emerging energy efficient technologies have been addressed by regulators

Table 1 summarizes the current product classification of HPWHs, CFLs, HIDs, and LEDs in Australia, the EU, and the US energy efficiency standards. We can see that in Australia, HPWHs, CFLs, and LEDs are considered to be separate product classes and are regulated as such. The EU regulates all the products as a general product class: HPWHs as water heaters, and all the lighting products as general lighting services. The US regulates HPWH as water heaters; and each lighting product has their own energy efficiency policy.

Table 1 Comparison of Product Classification in Australia, the EU, and the US

	Australia	European Union	United States
Heat-pump water heaters	Under consideration to be regulated separately AS/NZS 5125.1:2010 Heat pump water heaters - Performance assessment - Air source heat pump water heaters	Regulated as water heaters Lot 2: Water heaters and hot water storage tanks	Regulated as water heaters 10CFR 430.32(d) 2012
CFLs	Regulated separately from incandescent lamps AS/NZS 4847 Self-ballasted lamps for general lighting services	Regulated as general lighting services Lot 19: Domestic lighting: incandescent, halogen, and compact fluorescent lamps	Regulated separately from incandescent lamps Medium Base Compact Fluorescent Lamps 42 U.S.C. 6291 (16)
HIDs	Not regulated	Regulated as tertiary lighting Lot 8: Tertiary lighting	Under consideration to be regulated separately U.S. DOE (2010); U.S. DOE (2012); U.S. DOE (2013)
LEDs	Under consideration to be regulated separately	Regulated as general lighting services Lot 19, part 2: Directional lighting: luminaires, reflector lamps and LEDs	Not regulated

Source: E3, ECEEE, and DOE websites

We examine each policy in more details in the following in order to identify the pros and cons of each decision.

Heat-pump Water Heaters

Australia

In 1999, Australia introduced Minimum Energy Performance Standards (MEPS) for electric storage water heaters, with changes in 2005. The original product class was main pressure (unvented displacement) water heaters. In 2005, vented (low pressure) water heaters and heat exchange water heaters were added [9]. MEPS for gas water heaters are approved but not yet implemented in all jurisdictions [5]. HPWHs are exempt from the tank heat loss MEPS that apply to electric storage water heaters, provided they meet certain criteria for 'renewable energy' contribution under Australian Standard AS4234 [4]. As sales of HPWHs increase, so does the importance of achieving a satisfactory level of energy efficiency, together with an acceptable level of product performance. Australia plans to introduce MEPS for HPWHs by the end of 2013 to take effect in mid-2014 [5]. So far, Australia has developed three standards to determine the energy performance of heat pump water heaters [8]:

- AS/NZS 5125 (Heat pump water heaters – performance assessment)
- AS/NZS 4234 Appendix H (Air source heat pump water heater task performance evaluation)
- AS/NZS 2712 Appendix H (Test for air source heat pump water heater low temperature classification)

Water heating -- the second biggest contributor to the residential sector's energy use in Australia -- accounts for about 22% of residential energy use in 2010. From 2007 to 2009, Australia's Equipment Energy Efficiency (E3) Program investigated the possibility of improving the efficiency and performance of heat pump water heaters [5], [33].

European Union (EU)

There are five stages for the Energy-using Products (EuP) policy making process: 1) product study; 2) consultation forum and proposal; 3) draft regulation; 4) regulation committee approves the draft regulation; and 5) final regulation. Water heater policy making is still at stage 2 - consultation forum and proposal [12]. A list of principles for categorization were found in the existing EU product and building standards, which together give the policy makers an understanding of the technical diversity and the various features of water heating equipment in the EU:

- Fuel type (gas, electric, solar, heat pump)
- Functionality (output)
- Storage type (instantaneous and storage)
- Power/capacity class (in kW, residential/commercial)
- Water heater flue gas/air intake system
- Burner flue gas/air intake configuration
- Condensation
- Boiler water temperature control
- Burner power control system
- Mounting position
- Emission rating (NOx, CO)
- Ignition type
- Pump type
- Materials
- Statistics classification

For some smaller market segments, the current harmonized test standards are not fully appropriate. They measure energy efficiency and performance in some way but would require a more substantial update for heat pump water heaters to be in line with the above. Further study would be required to explore the possibilities of approximating the tapping pattern approach from the energy efficiency and performance parameters that are currently tested as a provisional measure. The relevant EN harmonized product test standards for heat pump water heaters addressed in mandate M204 is EN 255 [1997]. [30], [34]

The EU efficiency metrics is water heating energy efficiency (ηwh), that is, the ratio between the useful energy provided by a water heater and the energy required for its generation, expressed in %. Currently there is no MEPS for water heaters in EU, but the draft labeling regulation categorizes ten energy efficiency thresholds for each of eight declared load profiles [13].

United States (US)

For residential water heaters, standards were adopted in 1987 (effective 1990), with updates in 2001 (effective 2004) and 2010 (effective 2015) [22]. The original list of product classes for residential water heaters originally included: a) gas water heater; b) oil water heater; and c) electric water heater [19]. Heat pump water heaters were included in definition of water heaters in the original legislation and have been included together with electric resistance water heaters in the product class: electric storage water heaters. In 1994, two product classes were added: gas-fired instantaneous and electric instantaneous.

In a final rule published in the Federal Register on April 16, 2010, U.S. Department of Energy (DOE) determined that heat pump type water heaters with an integrated storage tank are a type of electric storage water heater, but that heat pump type water heaters without an integrated storage tank do not meet the definition of a "water heater" and are, therefore, not covered equipment under the Energy Policy and Conservation Act (EPCA).

In 2010, different standards were established (effective April 16, 2015) for two size ranges of electric storage water heaters. The efficiency metric is Energy Factor (EF). For those with rated storage volume >55 gallons, the minimum standard corresponded to efficiencies of heat pump water heaters: EF=2.057 – (0.00113 x Rated Storage Volume in gallons). For electric storage water heaters with rated storage volume </= 55 gallons, the minimum standard can be met by electric resistance water heaters, EF=0.960-(0.0003 x Rated Storage Volume in gallons).

Subsequently, some stakeholders (mostly electric utilities) expressed concerns that the standards for larger water heaters would interfere with electric thermal storage (ETS) programs that utility companies administer to manage peak load, and asked for a new product class, "grid-interactive water heaters," which would be electric resistance water heaters having >55 gallons of rated storage volume. DOE is considering that issue, with a public meeting planned for March 15, 2013 [25].

Compact Fluorescent Lamps

Australia

Since November 2009, self-ballasted compact fluorescent lamps (CFLs) in Australia have been required to comply with AS/NZS 4847.2 Self ballasted lamps for general lighting services - Minimum Energy Performance Standards (MEPS) requirements [6]. At the same time, certain general purpose incandescent lamps (tungsten filament and tungsten halogen) were also required to comply with MEPS that are set out in AS 4934.2 – incandescent lamps for general lighting services – in Australia [7].

General lighting service (GLS) lamps are the common pear-shaped incandescent lamps with tungsten filaments. They are the most inefficient yet widely used lamp in the residential sector. They continue to sell remarkably well because, if their energy costs are ignored, they appear cheap. More efficient lamps such as CFLs and halogen types are facing a number of problems breaking into the market. Currently the market price for a single CFL light bulb can be five times higher than a regular GLS lamp.

There are significant information failures and split incentive problems in the market for energy efficient lamps. Energy bills are aggregated and periodic and therefore do not provide immediate feedback on the effectiveness of individual energy saving investments. Consumers must therefore gather information and perform a reasonably sophisticated calculation to compare the life-cycle costs of tungsten filament lamps and CFLs. But many lack the skills. For others, the amounts saved are too small to justify the effort or they do not remain at the same address long enough to benefit fully from a long lived energy saving lamp. According to the 2006 census, 17% of people in private dwellings were at a different address 12 months earlier.

Both CFLs and lamp labeling have also had unfortunate histories. Early disappointments with aspects of the performance of CFLs – including problems with start up times, color and durability – have created uncertainties in the minds of users. Lamp labeling has evolved in a way that identifies the lighting power of a lamp with its energy use, inhibiting awareness of energy efficiency lighting options. It is estimated that, under business as usual (BAU) conditions, Australia's greenhouse emissions from lighting will increase by 150% from 1990 to 2010. Emissions will be approximately 32.4 Mt CO2-e in 2010 or 5.4% of Australia's projected total of 603 Mt CO2-e in 2010. By addressing market failures, the proposed measures will reduce greenhouse emissions by 28.5 Mt CO2-e over the period 2009 to 2020.

E3 initially proposed to phase out all incandescent lamps, albeit with long delays for certain types of lamp, to 2015. However this raised serious problems regarding the availability of replacement products, particularly for lighting systems that use dimmers, sensors, timers and other forms of electronic control. The proposal was revised to avoid potentially large costs of prematurely scrapping lighting assets. The revised MEPS proposal will:

- remove the least efficient incandescent lamps from the market, including the familiar pear-shaped tungsten filament lamps, otherwise known as GLS (incandescent) lamps of less than 150 watts;
- set standards for the efficiency and quality of CFLs; and,
- remove the least efficient extra low voltage converters (ELVCs)[1] from the market [3].

EU

The Ecodesign regulation on domestic lighting was adopted in 2008, and entered into force in 2009. The regulation covers incandescent, halogen, and compact fluorescent lamps, and is intended to phase out incandescent bulbs from 2009 to 2012.

It is appropriate to set specific requirements at a level that leaves alternative lamps available to service the entire installed stock of lighting equipment. In parallel, generic requirements should be set that are implemented by harmonized standards and that make new lighting equipment more compatible with energy-saving lamps, and energy-saving lamps compatible with a wider range of lighting equipment [18].

US

Lighting involves a variety of technologies and diverse lighting products. For fluorescent lamps, other than compacts, ballasts and lamps are regulated separately. Legislation in 1988 (amendment to National Appliance Energy Conservation Act, 1988) set standards for fluorescent lamp ballasts. The Energy Policy Act of 1992 (EPAct 1992) established standards for some lighting products, including general service fluorescent lamps, HID lamps, incandescent reflector lamps, and luminaires. The Energy Policy Act of 2005 (EPACT 2005) established energy conservation standards for compact fluorescent lamps, effective in 2006, and added additional lighting products, including ceiling fan light kits, illuminated exit signs, mercury vapor lamp ballasts, torchiere lighting fixtures, and traffic signals.

High Intensity Discharge Lamps

EU

[1] Extra low voltage converters (ELVCs) are used to provide power to low voltage halogen lighting systems.

The Ecodesign regulation on tertiary lighting entered into force in 2009 [12]. The legislation sets requirements for linear and compact fluorescent lamps without integrated ballast, for high intensity discharge (HID) lamps, and for ballasts and luminaires able to operate such lamps. However, there are several limitations, for instance very small HID lamps now increasingly popular in the retail sector are not covered [11].

It is important for this eco-design study that the definition of office lighting covers products with similar characteristics in order to be able to derive meaningful conclusions regarding design options, improvement potential and finally potential policy options. The above definition of office lighting serves right for this study as product groups that are functionally similar are envisaged, according to the Methodology study for EcoDesign of Energy-using Products (MEEUP) Methodology Report [29]. Consequently, a similar group of design options will apply to improve the environmental performance of these products. This study focuses on lighting equipment for ‘office work’ areas as they are functionally similar.

In Eurostat’s product-specific statistics for trade and production, office lighting luminaires can be reported in two manners:

- According to lamp technology; and
- According to the material from which the luminaires are made [28].

US

In 2010, DOE issued a determination that standards were justified for HID lamps. DOE assessed the potential energy savings for the lamps identified in the final coverage determination by analyzing product availability, potential lamp designs that improve efficacy, and other factors (such as the potential to serve as a substitute for other regulated lamp types). HID lamps can differ from each other based on a variety of characteristics:

- Ballast location
- Base type
- Bulb finish (clear or coated)
- Bulb shape
- Colored lamps
- Correlated color temperature (CCT)
- Directionality of lamps
- Lamps operated on electronic ballasts only
- Lamp operating orientation
- Lumens
- Luminaire characteristics (open or enclosed)
- Specialty applications
- Wattage

In 2012, DOE proposed equipment classes based on directionality, ballast location, CCT range and lumen range [24].

In 2013 interim analysis, the definitions of equipment classes were changed. DOE is considering exempting directional and self-ballasted HID lamps, so it dropped those factors, as well as ballast location. Proposed equipment classes are now based on CCT range, wattage, bulb finish (clear or coated) and luminaire characteristic (open or enclosed). Different lamp technologies are included in some equipment classes, and will be subject to the same standards (e.g., some metal halide and mercury vapor lamps). In summary, DOE is considering including in the scope of coverage for a standard:

- metal halide (MH) lamps with a rated wattage between 50W and 2,000 W, and CCTs from 2800 K through 6999 K
- mercury vapor (MV) lamps with a rated wattage between 50 W and 1,000 W and with CCTs from 3200 K through 6800 K, and
- high pressure sodium (HPS) lamps with a rated wattage between 50 W and 1,000 W and with CCTs from 1900 K through 2700 K.

DOE is considering excluding HID lamps designed and labeled for use with electronic ballasts only, directional HID lamps, self-ballasted HID lamps, colored MH lamps (CRI <40), electrodeless lamps, MV lamps intended for specialty applications, and high CCT lamps from the scope of coverage [26].

In Table 2, we group the major factors when these three economies consider how to classify an emerging technology. In general, the European Parliament and Council consider market size, environmental impact, and the potential to improve the environmental impact without imposing excessive cost [14]; DOE divides covered equipment into classes by the energy used, capacity, or other performance-related features that impact efficiency, and other factors such as the utility of the product to users (42 U.S.C. 6295(q)).

Table 2 Product Classification Considerations in Australia, the EU, and the US

Australia	European Union	United States
• Market size • Cost saving potentials • Energy consumption • Energy saving potentials • Existence of a market failure that justifies the Australian Government to intervene • Greenhouse gas saving potentials • Industry impact, especially on local manufacturing • Net public benefit, demonstrated by a cost-benefit analysis • Test standards, national or international	• Market size • Energy system(s) • Environmental impact • Existing EU, Member State, or third country legislation • Test methods • Product characteristics • Materials	• Market size • Capacity, size, volume • Energy used (e.g., electricity, gas, oil) • Other performance-related features that impact efficiency • Other factors such as the utility of the product to users

Source: [31], [14], and US rulemakings

Two possible policy approaches

There are two ways to regulate LEDs. One is to regulate LEDs as general lighting services by setting a single efficiency requirement common to all technologies (Scenario 1); the other option is to regulate incandescent, CFLs, and LEDs each as a separate equipment class with its own efficiency requirement (Scenario 2). Scenario 1 has the potential to lift the whole lighting market to a higher efficiency level, at the risk of eliminating less efficient technologies (e.g., incandescent lamps and perhaps CFLs). Figure 1 illustrates the impacts of the two scenarios. In Scenario 1, as the energy efficiency level was set at the average level across the entire general service lighting sector, CFLs and incandescent lamps would be required to improve efficiency in order to meet the threshold. In Scenario 2, on the other hand, each product class (e.g., lighting technology) has their own separate minimum efficiency requirement. Although the efficiency requirement for LED would be higher than that in Scenario 1, the efficiency levels for CFLs and incandescent lamps would be set at lower levels, because at present those technologies are much less efficient than LEDs. Factors to consider are the tradeoffs between the utility provided by keeping a wider range of technologies, compared to the limitations that Scenario 2 places on energy efficiency. In other words, Scenario 2 retains less efficient technologies.

Practical and economic matters also need to be considered. Replacing all incandescent lamps with CFLs was not practical without sacrificing some utility when CFLs that could be dimmed were not available. The costs of replacing existing lighting infrastructure with different technologies can be high. If replacing one technology with another, the effort may involve more than substituting lamps, and could include replacing fixtures. Those costs should be included in estimating cost-effectiveness of policies.

According to a recent study of technical potential by the Lawrence Berkeley National Laboratory, if all lighting reached the same efficiency level in the range of LEDs (100 lm/W), rather than separate efficiency levels at 60 lm/W (CFL) and 15 lm/W (incandescent), respectively, Australia could save 2 TWh energy, and the EU and the US could each save 29 TWh in the year 2020 [16]. The total energy savings in those three economies would be equal to the elimination of 12 coal fired power plants [27]. The cost-effective potential was estimated to be less, 0.4 TWh in Australia and 20 TWh in the EU in the year 2020, and no savings in the US at a cost of conserved energy below $0.01/kWh. The baseline case included phase-out of incandescent lamps s by 2030 [15].

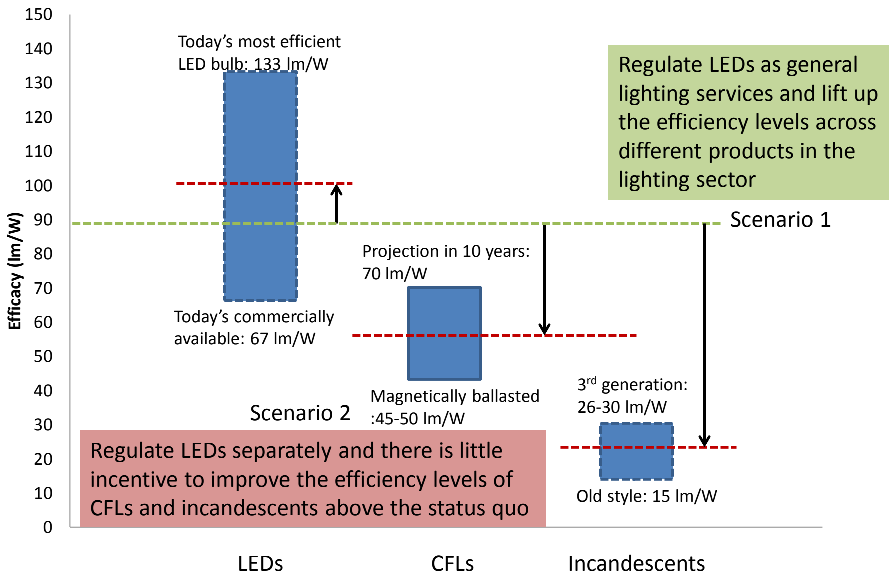

Figure 1 Illustration of the Impacts of Different Product Classification Scenarios on Lighting Products Efficiency Levels

Source: [32] and [2]

With respect to market developments, the choice of regulation can have significant effects on markets and stakeholders . One path may stratify the status quo, while the other may encourage more development and innovation.

As can be seen with past examples regarding advances in lighting technologies, the treatment of CFLs as a distinct product class has had a significant impact on the market. This treatment, and the promotion of CFLs by market transformation organizations (including electric utilities and state agencies) in the US, gave rise to a new group of product manufacturers and fostered competition. The widespread demand for CFLs in the US allowed smaller manufacturers to enter the market earlier in its development, changing the dynamics in a market previously dominated by three major manufacturers and a handful of no-name producers competing in the sale of a commoditized product. A few of the new market entrants eventually became major CFL suppliers that directly challenged the established manufacturers for market share. They also drove product innovations, including the “spiral” design, better electronic ballasts, and smaller diameter tubing. However, the challenge with CFLs which regulators had difficulty addressing was and still is product quality. With many manufacturers entering the market, price became the one distinguishing factor, and the market experienced a “race to the bottom” in terms of price and product quality.

Some similarities can be seen with the developing market for LEDs. Since their introduction up to now, the LEDs market is dominated by several LED chip manufacturers, and a few large lamp manufacturers. Increasingly, there are more entries by smaller manufacturers into the market, most competing on price. However, because LEDs can require sophisticated electronic drivers, there are more electronics manufacturers interested or are exploring entry into this market. Their entry could help to drive product innovation and accelerate advances in lighting derived from the electronics arena. The challenge for regulators once again is to anticipate this market shift, and design regulations in such a way to encourage innovation and advancement, while preventing the proliferation of poor quality products that can turn consumers away from this significant innovation. We also note that not only LEDS, but also incandescent and some CFLs are now innovating, some to twice past efficacy levels.

Conclusion

LED is an emerging technology with a promise of significant energy savings potential. In considering how to regulate this technology, regulators may want to take into account of developments internationally, as well as the characteristics of their own market. In fact, regulators outside of the EU and US may find it advantageous to take into account of regulations that are under development in both of these regions to ensure alignment where possible, as well as considering domestic manufacturing and market characteristics.

For regulators wishing to maximize competition in their market, they may want to consider regulating LEDs as a separate product class. The full implications of this approach on the lighting market may not be known, however, they can include more consumer choice, potentially a higher cost for the service (but possibly lower lifecycle costs in the long run) and perhaps a limit on energy savings for lighting as a whole. Those who choose to take this path have a number of existing MEPS and other model regulations in place elsewhere internationally that can be adopted for the different lighting technologies. It should be noted that regardless of approach, alignment with international norms can also lower market entry costs for manufacturers and risks for S&L policies.

On the other hand, regulators can regulate incandescent lamps, CFLs, and LEDs together as a common lighting service. This can have the effect of minimizing (or providing more certainty about – in the case of incandescent phase-out) market disruptions. If a more stringent standard level can be reached by innovation in competing technologies, it can also have the effect of increasing innovation in product performance for those technologies competing with the emerging technology (as can be seen in CFL and recent incandescent developments). Depending upon the standard level, however, this can also mean a slower path to maximized energy savings. Market disruptions can be a positive or negative force, depending on whether or not consumers can be adequately prepared for such events through outreach efforts or clear and effective message on the label, for example. Consumers who are not prepared for new technologies tend to distrust them more, and are less likely to adopt them early.

Whichever regulatory approach is taken, specifications (e.g., performance, lifetime, dimming) and safeguards are required to prevent “unintended affects”, such as a “race to the bottom competition,” where quality is sacrificed to achieve lower equipment price, and to ensure consumer protection against poor performing products. Table 3, below lists a number of factors that regulators may want to take into consideration, and possible effects, depending on the chosen approach.

Table 3 Factors to Consider In Product Classification for Standards and Labels

Considerations	Lighting services as one class (Scenario 1)	Separate Classes by Technology (Scenario 2)
Service provided	All classes provide a common service	Classes may provide different services
Utility	Some utility in common among all classes	Classes may provide different utilities
Energy savings	Including substitution of emerging technology for existing	Within each class
Innovation	Interaction across classes	Within each class
Specifications beyond EE needed	Maybe (other parameters such as color and dimming)	Yes

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A preliminary study of lighting energy performance in houses with various window systems

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Abstract

This paper presents a preliminary study on the impact of windows on energy performance in a detached house in Sweden. The parameters studied include window sizes, thermal and visual transmittances, solar gains, as well as one shading device. The energy consumption of electrical lighting system was the main factor to be first investigated. Furthermore, the heating and cooling demands were also assessed to demonstrate an entire profile of energy performance with the occurrence of various window systems and lighting conditions. Based on typical climate zones in Sweden, three locations (Umeå, Stockholm and Malmö) have been selected as the representatives. DesignBuilder (+EnergyPlus), a state-of-the-art package, was used to dynamically simulate environmental effect and energy performance. A clear relationship between window use and lighting energy performance has been achieved. The final results could be used for supporting earlier stage house design in northern Europe.

1. Introduction

The window system (including rooflight) has been considered as one of the most significant building components when evaluating energy and environmental performance of a house [1]. The indoor environment and energy use have a substantial relationship with window characteristics (thermal transmittance, solar gain, visual transmittance, etc.) and configurations [2]. Generally, the evaluation of windows is carried out in a specific built environment, because their performances are also dependent on the building type and outdoor climate [3].

Daylight (skylight and sunlight) has been regarded as one indispensable environmental factor in residential buildings [4]. It can illuminate the indoor tasks, reduce electrical lighting use and save energy, improve human health and well-being on the ground of physiological and psychological aspects [4, 5]. Windows could be used as an efficient approach to deliver daylight into buildings [6]. For the window use and lighting energy savings, most of the previous studies were completed in commercial and public buildings [7]. It might be determined by the scale of electrical lighting systems and their energy consumptions in these spaces. Recently, this topic in residential buildings has received more attentions. In Europe, a study [8] has been conducted to investigate the impact of windows on overall energy use (lighting, cooling, heating) in a single family house (with 20% window-to-floor area ratio) located in different cities. The findings show that the window is the most energy-efficient way to provide biological light levels (500-2500 lx). Even though the basic conditions for energy analysis are significantly oversimplified, this study still expresses a clear relationship between windows and electrical lighting savings. Another Swedish study [9] in passive houses pointed out that enlarging a north glazing was actually a possible solution to increase the daylight utilization and save energy with the occurrence of energy-efficient windows. The integration of daylighting and artificial lighting systems has been apparently suggested in several important building standards in order to achieve an energy-efficient building [10, 11].

In addition, window energy performance relating to thermal environment could be another crucial issue concerning the house owners or builders. The thermal transmittance of the window (even one with a good performance) could be four to five times larger than a well-insulated wall [3]. Overall, the heat loss from windows could even achieve a level of around 1/3 of the total energy loss in a typical

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residential building [12]. On the other hand, windows can make contributions to the energy gains by allowing solar radiation into the houses, which at the same time increases the risk of overheating [3]. An optimal energy balance for windows would be a basic requirement for the houses with good energy performances.

This paper presents a preliminary study on the impact of windows on energy performance in houses in Sweden. The parameters studied were composed of window sizes, thermal and visual transmittances, as well as one shading device. The electrical lighting energy consumption was the main factor to be first investigated. Furthermore, the heating and cooling demands were also calculated to demonstrate an entire profile of energy consumptions with the occurrence of various window systems and lighting conditions. In terms of typical climate zones in Sweden, three locations have been selected as the representatives. DesignBuilder (+EnergyPlus), a state-of-the-art package, was used to dynamically simulate environmental effect and energy. The achieved results would be used for supporting house design at the earlier stage.

2. Methodology

This section comprises the introductions of house model and locations, window systems and simulation tools.

2.1 House model and locations

A one-story detached house (Figure. 1) was studied, which was built in terms of the basic Swedish house models [13]. With a floor area around 130 m^2 and south orientation, the house has a rectangular plan (length 19 m; width 7 m). The wall of the ground floor is 3.3 m while the pitched roof has a slope angle of 45°. No internal partitions have been used. Only the façade below the roof has been installed windows. The thermal properties (U-value) of the house envelop are the follows: U(wall) = 0.15 W/m^2K; U(roof) = 0.1 W/m^2K; U(ground floor & external floor) = 0.2 W/m^2K.

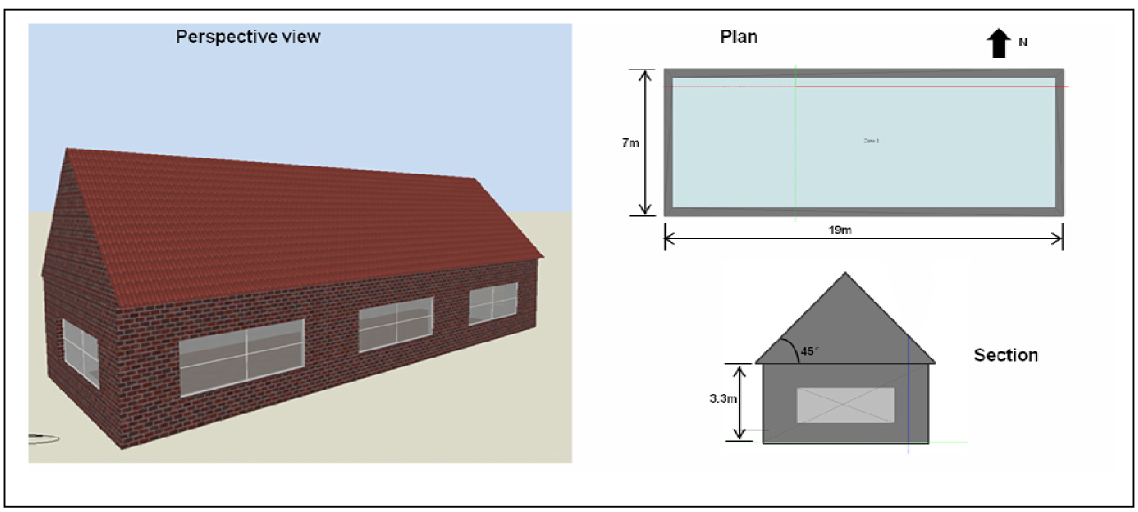

Figure. 1: The Swedish house model studied in this paper.

With respect to the climate zones in BBR 2009 [14], three Swedish cities were chosen as the house locations: Umeå (Climate zone I; Latitude 63.80°, Longitude 20.28°); Stockholm (Climate zone II; Latitude 59.65°, Longitude 17.95°); Malmö (Climate zone III; Latitude 55.55°, Longitude 13.37°). Clearly, a relatively cold climate was the dominant weather condition.

2.2 Window systems

According to thermal transmittances, two different windows were analyzed in the house such as common window and energy-efficient window. The common and energy-efficient windows used in the study consisted of clear-glass panes and low-e glass panes respectively. The thermal, solar energy and visual transmittances of the two windows are given in Table. 1.

Moreover, this study also assessed the effect of window sizes at facades below the roof. Eight various window areas were studied defined by the WWR (window-to-wall ratios): 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%. A medium-opaque roll shade was used as the basic outside shading device for each window if it is required.

Table. 1: The thermal, solar energy and visual transmittances of two window systems.

Name	U(glazing)-value (W/m^2K)	U(frame)-value (W/m^2K)	g-value	Visual Transmittance
Common Window	1.60	2.00	0.70	0.74
Energy-efficient window	0.80	1.50	0.50	0.62

2.3 Simulations

The energy performance of the house models was simulated using DesignBuilder (+EnergyPlus). It is a dynamic simulation package and could provide a comprehensive range of energy consumption and environmental data (heating, cooling, lighting, ventilation, etc) shown in annual, monthly, daily, hourly or sub-hourly intervals [15].

The annual electrical lighting demand (kWh/m^2) was the first important component of energy consumption in this study. For the lighting analysis, only one lighting control zone and the general lighting have been set across the entire rectangular ground floor in order to simplify the environmental influence. The target illuminance level was 500 lx, which is regarded as the minimum lighting level concerning the issues of visual purposes and human well beings in residential buildings [8]. A working plane (0.8 m above the floor) was used for daylighting and lighting calculation. The electrical lighting was controlled through a linear model corresponding with the daylight illuminance level. The lighting power density was set as 17 W/m^2 [16]. Also, the roll shading device will be operated in terms of visual comfort (the maximum allowable glare index = 22, facing south) [16].

The annual heating and cooling demands (kWh/m^2) were the second component of energy consumption. Even though it is not necessary to adopt cooling systems in residential buildings under Swedish climatic conditions, the cooling load was still calculated to clarify the impact of shading device. For thermal environment, the set points of 21°C and 26°C were used for heating and cooling systems respectively, which were based on energy-efficient use [6, 14]. Similar to lighting, the house has only one thermal zone in which no internal heat gains and mechanical ventilations have been considered. Most of the settings have been simplified to reduce the environmental effect.

3. Results and Discussions

The simulated electrical lighting, heating and cooling demands in the house model with various window systems were analyzed in this section.

3.1 Common Windows without Shading Devices

Figure. 2 shows the annual lighting and heating load (kWh/m^2) in a house with common windows (U(glazing) = 1.6 W/m^2K) and eight various window sizes at three Swedish locations. No shading devices are included. Generally, the annual lighting energy consumption slightly decreases with the increase of window area of the four facades at all the locations. For each WWR (window-to-wall ratio), no big differences of lighting load could be found between the three different locations. For example, houses with a WWR of 10% in Umeå, Stockholm and Malmö have annual lighting loads of 36.07, 35.18 and 34.68 kWh/m^2 respectively, while the three values will be changed into 31.46, 30.57 and 29.96 kWh/m^2 when the WWR becomes 80%. This could be explained by a fact that overcast sky condition dominates most of Swedish cities. The heating load, nevertheless, shows an opposite variation that the increasing window areas increase the heating energy use when the WWR is larger than 20%. The small window areas (WWR 10% and 20%) have a relatively similar heating load in houses. Interestingly, the curve of heating load at each location approximately parallels with others and its distribution well corresponds with the latitude and basic climate condition. The northern city Umeå sees the maximum heating energy consumption while the southern city Malmö has the minimum value. With a location in the middle, Stockholm has a medium heating load in the house.

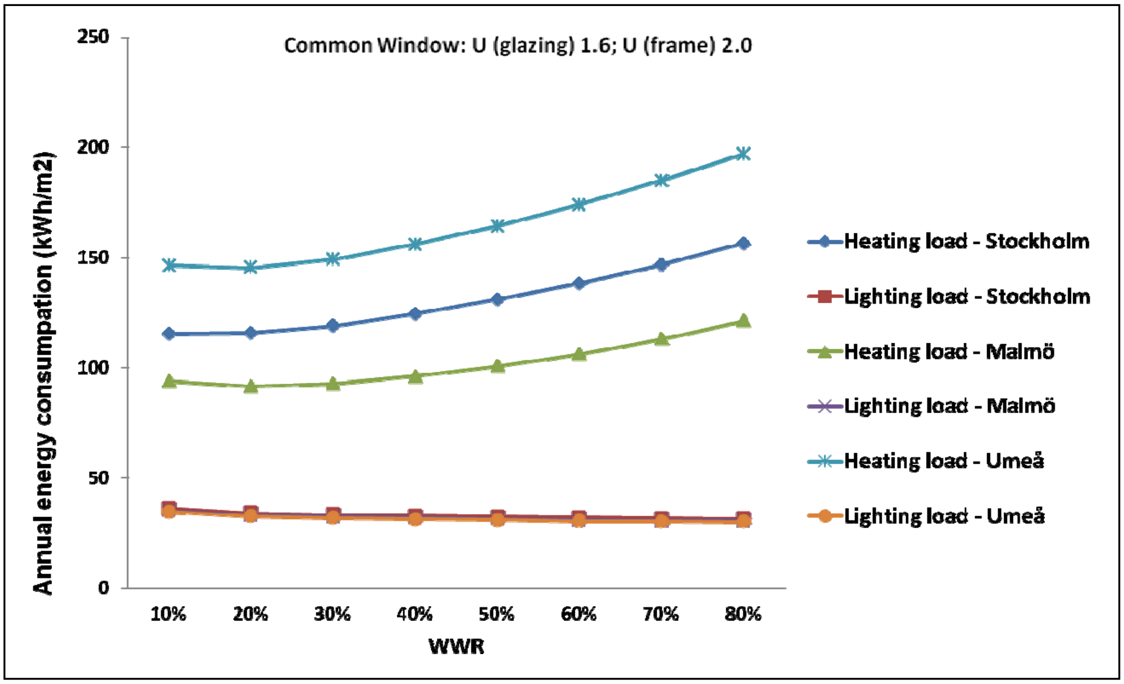

Figure. 2: The annual lighting and heating load in houses with various window areas (common window; no shading).

Table 2: The percentage differences of lighting and heating load between various window areas (common window; no shading).

R value (%)									
WWR		**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
Lighting load	**Stockholm**	0.0	-5.7	-7.7	-8.8	-10.2	-11.5	-12.4	-12.8
	Malmö	0.0	-5.7	-7.9	-9.1	-10.4	-11.8	-12.8	-13.1
	Umeå	0.0	-6.1	-8.2	-9.5	-10.8	-12.2	-13.2	-13.6
Heating load	**Stockholm**	0.0	0.3	3.0	7.7	13.4	19.8	27.1	35.3
	Malmö	0.0	-2.4	-1.2	2.4	7.2	13.0	20.5	29.1
	Umeå	0.0	-0.6	1.9	6.5	12.3	18.8	26.4	34.7

Taking the lighting load or heating load at WWR 10% as a reference, R is defined as the percentage difference of energy consumption between other WWR values and the 10% by the equation (1):

$$R = \frac{E_{lighting\ (heating),n} - E_{lighting\ (heating),10\%}}{E_{lighting\ (heating),10\%}} \times 100\% \qquad (1)$$

where, $E_{\text{lighting (heating)},n}$ is the lighting load or heating load when the WWR = n;

$E_{\text{lighting (heating)},10\%}$ is the lighting load or heating load when the WWR = 10%;

n is the WWR value (from 10% to 80%, with a step of 10%).

Table. 2 gives the R values of lighting and heating load in a house with common windows and eight various window sizes at three Swedish locations. It could be clearly found: for the WWR > 50%, the reduction rate of lighting energy use is less than the increase rate of heating energy use with an increasing window area; for the WWR < 50%, the decrease rate of lighting energy use is larger than the increase rate when window area tends to bigger. Moreover, the absolute percentage of lighting load reduction is similar to the absolute percentage of heating load increase for the half wall and half window configuration (WWR 50%). These indicate that increasing the sizes of smaller common windows in a range would benefit both the energy performances and environmental requirements.

3.2 Energy-efficient Windows without Shading Devices

Figure. 3 displays the annual lighting and heating load (kWh/m^2) in a house with energy-efficient windows (U(glazing) = $0.8W/m^2K$) and eight various window sizes at three cities in Sweden. The house windows have no shading devices.

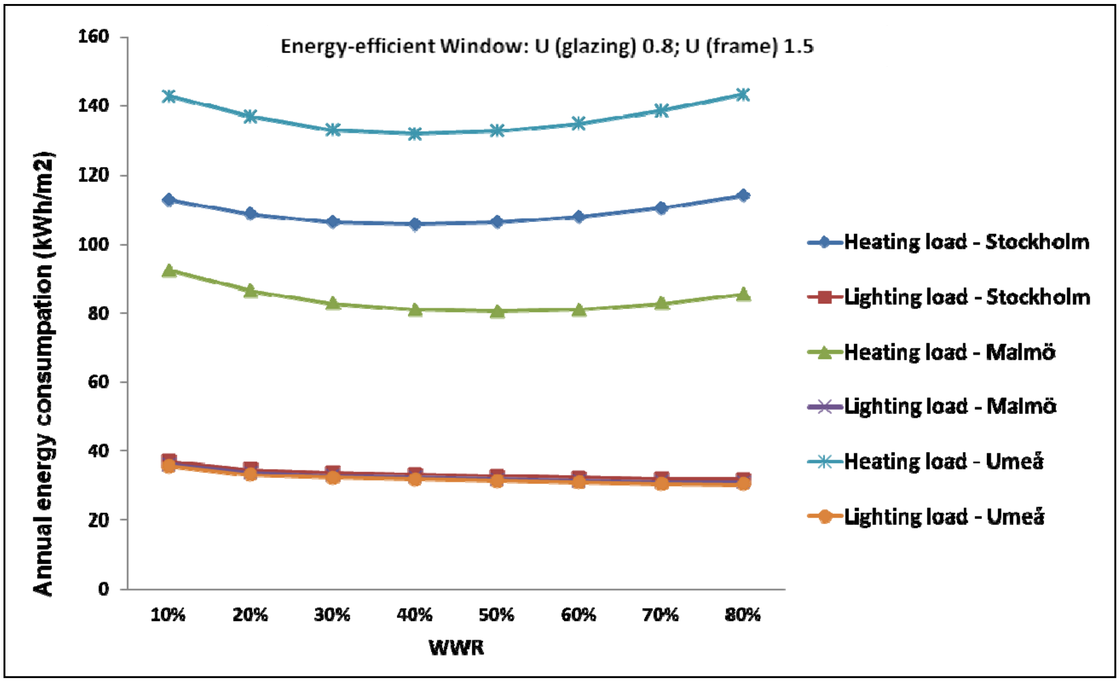

Figure. 3: The annual lighting and heating load in houses with various window areas (energy-efficient window; no shading).

Like the common window, the increasing energy-efficient window sizes still continuously decrease the lighting energy consumption. The three Swedish locations also see a similar lighting load at each window size. The WWR 10% has the maximum lighting load (around 36 kWh/m^2) while the maximum lighting energy use (around 30 kWh/m^2) can be found at WWR 80%. However, the variations of heating load express a different trend compared with the common window. With the increase of WWR value, the heating load slightly falls and reaches the bottom at 40% or 50% and then slowly goes up. The location effect keeps the same distribution for heating load curves: Umeå, Stockholm and Malmö have the maximum, medium and minimum heating energy use.

The R values of energy-efficient windows are given in Table. 3. In general, the reduction rates of lighting load are bigger than the varying rates of heating load with the increasing window areas. The heating energy use at WWR 10% is larger than most of the values with a larger window area except for the WWR 80% at Umeå and Stockholm. The R values of Malmö completely support the utilization of larger energy-efficient window systems. At Stockholm, houses with 30%, 40% and 50% WWR could save 6% heating consumption in the house with the 10% WWR. Combined with lighting energy use, the 50% and 40% WWR could be the most efficient. Similarly, the proper values at Umeå are 50% and 40% whilst Malmö has two larger ones of 50% and 60%.This could be explained by a fact: the energy-efficient windows with a lower heat loss (lower U value) increase the possibilities to use a larger window, which allows more solar gains. A similar result can be found in a study of the window thermal properties and sizes in passive houses [9].

Table. 3: The percentage differences of lighting and heating load between various window areas (energy-efficient window; no shading).

		R value (%)							
		10%	20%	30%	40%	50%	60%	70%	80%
Lighting load	Stockholm	0.0	-6.5	-8.7	-9.8	-11.2	-12.6	-13.5	-13.9
	Malmö	0.0	-6.5	-8.8	-10.0	-11.5	-12.9	-13.9	-14.3
	Umeå	0.0	-7.1	-9.5	-10.7	-12.2	-13.6	-14.6	-15.0
Heating load	Stockholm	0.0	-3.6	-5.6	-6.3	-5.7	-4.3	-2.0	1.2
	Malmö	0.0	-6.3	-10.3	-12.2	-12.7	-12.2	-10.3	-7.3
	Umeå	0.0	-4.2	-6.8	-7.6	-7.0	-5.5	-3.0	0.3

3.3 Common Windows with Shading Devices

Figure. 4 indicates the annual lighting and heating load (kWh/m^2) in a house with common windows (U(glazing) = 1.6 W/m^2K) and an outside roll shade and eight various window sizes at three cities in Sweden.

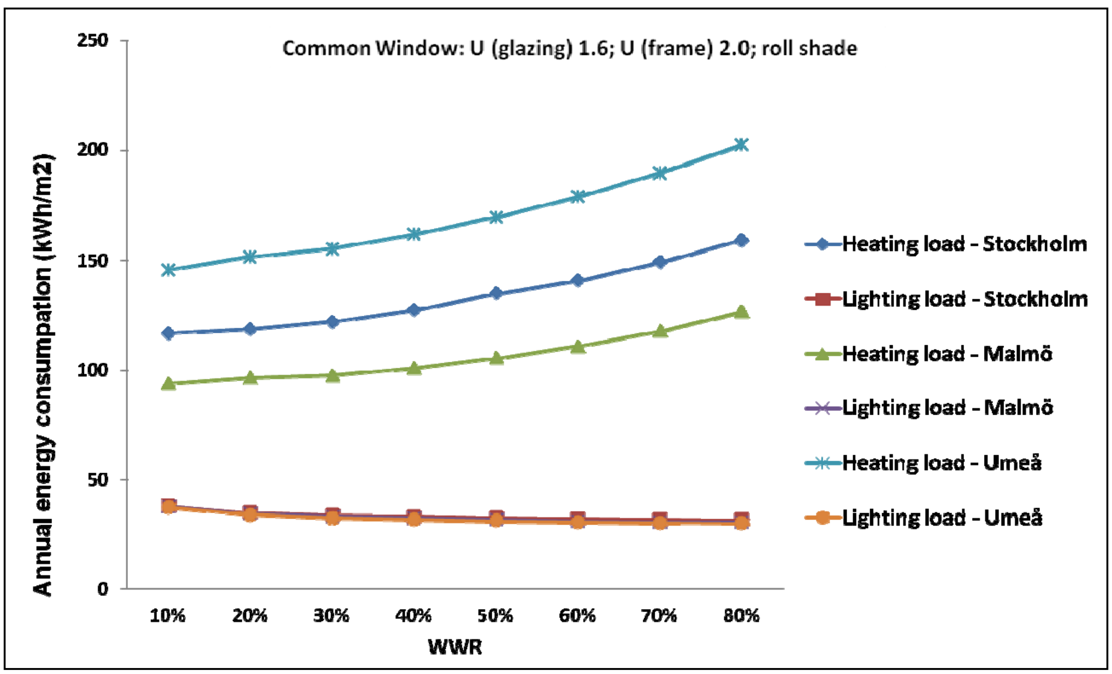

Figure. 4: The annual lighting and heating load in houses with various window areas (common window; with a roll shade).

For the common windows with a roll shading device, the general varying trends of lighting and heating load with an increasing WWR value still keep the same as the windows without any shading devices. When the window area tends to larger, the electrical lighting energy consumption decreases while the heating load increases. According to Table.4, comparatively, the reduction rate of lighting load and the increasing rate of heating load at each WWR are both bigger than the values of common windows without shades (in Table.3). This could show that the roll shade makes the lighting and heating load receive more sensitivity to the change of window area. Even though the shading operation is controlled by visual comfort as mentioned above, the roll shade could also block some solar gains, especially for larger windows.

Table. 4: The percentage differences of lighting and heating load between various window areas (common window; with a roll shade).

R value (%)									
		10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
Lighting load	**Stockholm**	0.0	-7.7	-10.9	-12.5	-13.7	-15.3	-16.3	-16.7
	Malmö	0.0	-8.5	-12.1	-14.1	-16.1	-17.5	-18.4	-18.8
	Umeå	0.0	-8.9	-12.7	-14.7	-16.6	-18.2	-19.2	-19.5
Heating load	**Stockholm**	0.0	1.5	4.4	9.0	15.6	20.7	27.9	36.3
	Malmö	0.0	2.8	4.1	7.7	12.4	18.1	25.4	34.8
	Umeå	0.0	3.9	6.5	10.9	16.4	22.8	30.2	38.9

3.4 Energy-efficient Windows with Shading Devices

Figure. 5 gives the annual lighting and heating load (kWh/m^2) in a house with energy-efficient windows (U(glazing) = 0.8 W/m^{2}K) and an outside roll shade and eight various window sizes at three cities in Sweden. The percentage differences of lighting and heating load (R value) between various window areas of energy-efficient windows are given in Table. 5. The variations of lighting and heating load are similar to the energy-efficient windows without any shading devices (in Figure.3 & Table.3). The WWR 40%, 50% and 60% would promote an optimal energy performance in houses when only taking into account lighting and heating energy use. For the lighting and heating load with energy-efficient windows, the roll shade also brings in higher sensitivity to the varying window area.

Table. 5: The percentage differences of lighting and heating load between various window areas (energy-efficient window; with a roll shade).

R value (%)									
		10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**
Lighting load	**Stockholm**	0.0	-8.0	-11.4	-13.0	-14.6	-16.0	-17.0	-17.4
	Malmö	0.0	-8.3	-12.3	-14.4	-16.4	-18.0	-19.0	-19.3
	Umeå	0.0	-8.9	-12.9	-15.0	-17.1	-18.7	-19.8	-20.2
Heating load	**Stockholm**	0.0	-2.2	-4.0	-4.7	-4.3	-3.1	-0.9	2.6
	Malmö	0.0	-3.3	-6.8	-9.0	-9.8	-9.6	-7.9	-4.3
	Umeå	0.0	-1.4	-3.5	-4.5	-4.3	-3.2	-1.0	2.7

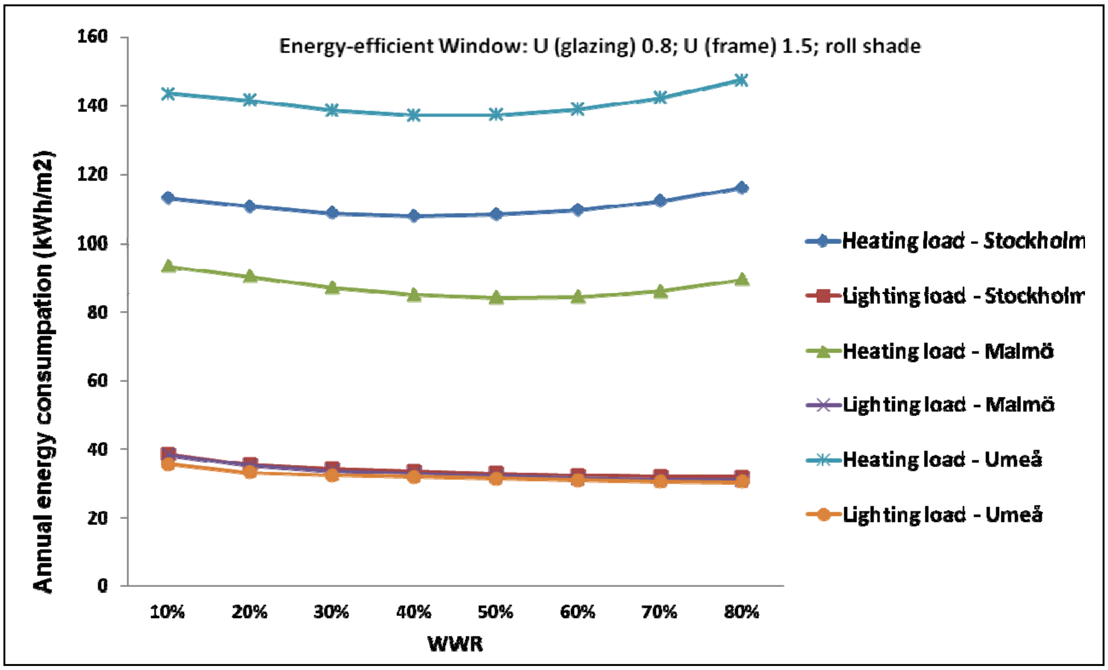

Figure. 5: The annual lighting and heating load in houses with various window areas (energy-efficient window; with a roll shade).

3.5 Comparisons between various windows

This section has the comparisons of energy performance (lighting, heating and cooling) between the various windows analyzed above.

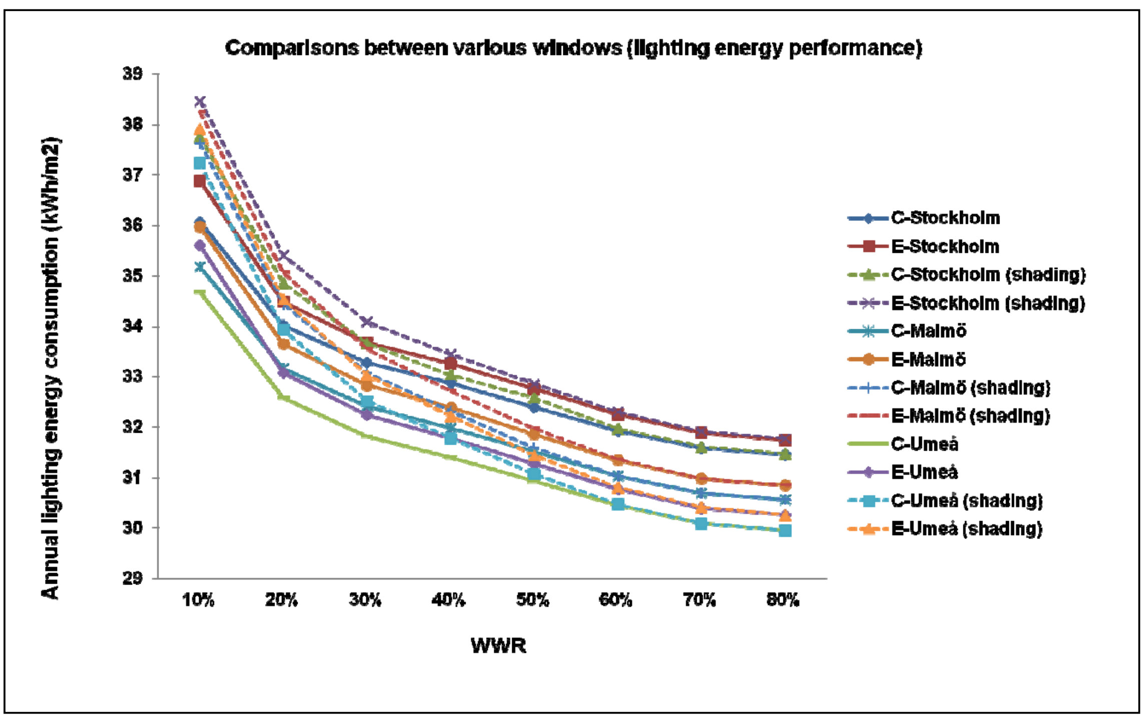

Figure. 6: The comparison of annual lighting energy consumption between various window systems (C: common window; E: energy-efficient window).

First, Figure. 6 shows the comparisons of annual lighting load (kWh/m^2) between various windows. Apparently, the lighting load of each window varies in a similar trend. The trend can be regressed into a power equation: $y = ax^{-b}$ (2), where, y is the lighting load (kWh/m^2); x is the WWR; a, b is the constant. For the small and medium window sizes (WWR < 60%), the windows with a roll shade give rise to a higher lighting energy consumption than the windows without shading devices. The difference of lighting load between the two windows will decrease with the increase of WWR. For the larger windows (WWR 60%, 70% and 80%), roll shade takes little effect on the lighting load. Obviously, the maximum lighting load is found for the energy-efficient window with a roll shade at Stockholm while the common window at Umeå has the least lighting energy consumption.

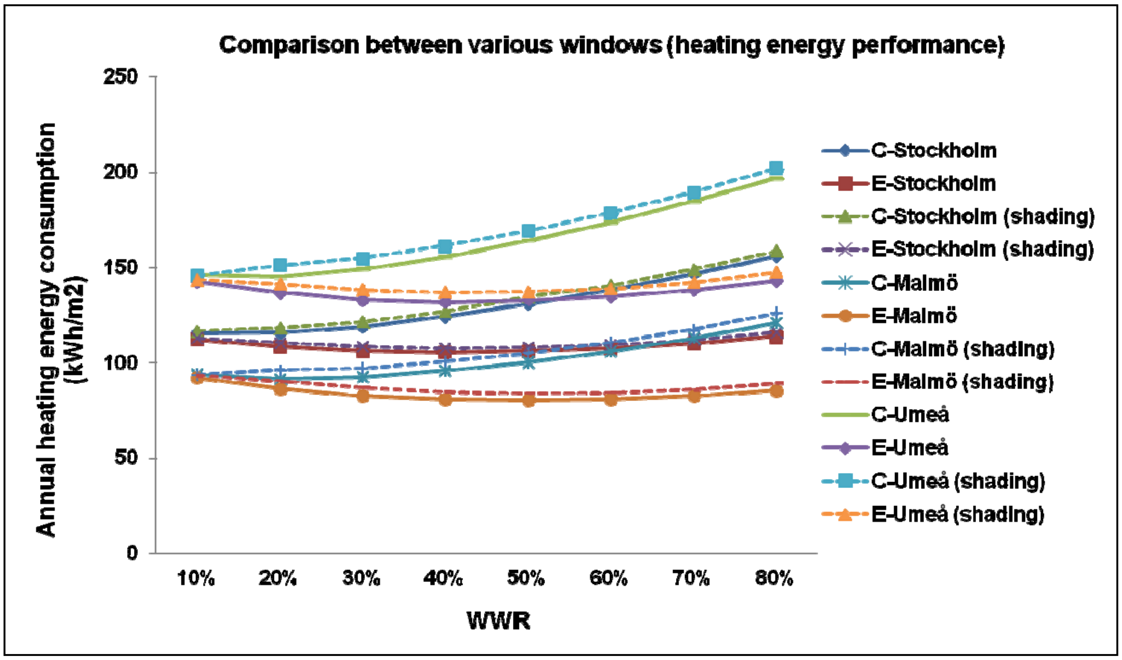

Figure. 7: The comparison of annual heating energy consumption between various window systems (C: common window; E: energy-efficient window).

Next, Figure. 7 demonstrates the comparisons of annual heating load (kWh/m^2) between various windows. It can also be found that the window with a roll shade at each location has a bit higher heating load than the window without shading devices. Clearly, the energy-efficient windows achieve a lower heating energy use than the common windows. Except for the smallest window size (WWR 10%), the differences of heating load between the two windows increase with an increasing window area. The largest window area (WWR 80%) sees the maximum absolute differences: 42.5 kWh/m^2 (Stockholm), 36.2 kWh/m^2 (Malmö) and 54.1 kWh/m^2 (Umeå).

Finally, Figure. 8 shows the comparisons of annual cooling load (kWh/m^2) between various windows. As mentioned in Section 2.3, the cooling system is not a crucial issue in Swedish residential buildings. The cooling load is only used for assisting the assessment of shading system here. The roll shade studied could substantially reduce the cooling energy consumption, in particular for the larger window sizes (WWR > 40%). The higher daylight levels would occur during the cooling season (e.g. summer) in Sweden. So, the roll shade used for visual comfort could also reduce the potential of overheating.

4. Conclusions

In this study, the effect of window properties (sizes, thermal and visual transmittances, as well as solar gains) and one shading device on energy performances was investigated in a medium detached house located at three different Swedish sites. The lighting energy consumption was the fundamental topic studied while the heating and cooling demand were also calculated to give a whole view of energy performance. Several main findings are mentioned as the follows:

(1) It is possible to increase daylight availability and reduce electrical lighting use by increasing window size across the façades in houses in high latitude areas of Europe. But, an energy balance between lighting and heating load has to be considered at the same time;

(2) For general windows with common thermal and visual properties, the increased window size would allow more daylight availability but at the same time increase the heating energy consumption. The area of façade window could be lower than the area of half wall in order to achieve a good energy balance between lighting load and heating load in houses;

(3) For special windows with high energy efficiency, a larger window size (around or more than half wall area) could be an optimal solution to achieve a reasonable energy consumption and more daylight availability;

(4) For lighting performance, the shading devices significantly influence the windows with small sizes while no clear impact could be found for the larger windows (especially for the WWWR > 50%);

(5) For thermal environment, the shading devices would not take substantial effect on heating systems while the cooling load could be clearly affected, particularly for the large window;

(6) An energy-efficient window could not only give rise in a better energy performance but also bring in more flexibility for the house design than the common window.

Limitations: this study was completed in a simply house model. Some environmental conditions (e.g. internal gains and ventilations) have not been included into the whole simulations, which might result in some differences of window energy performances. These works would be the centre topic carried out in the next stage. In addition, the economic issue would be studied and discussed in the future.

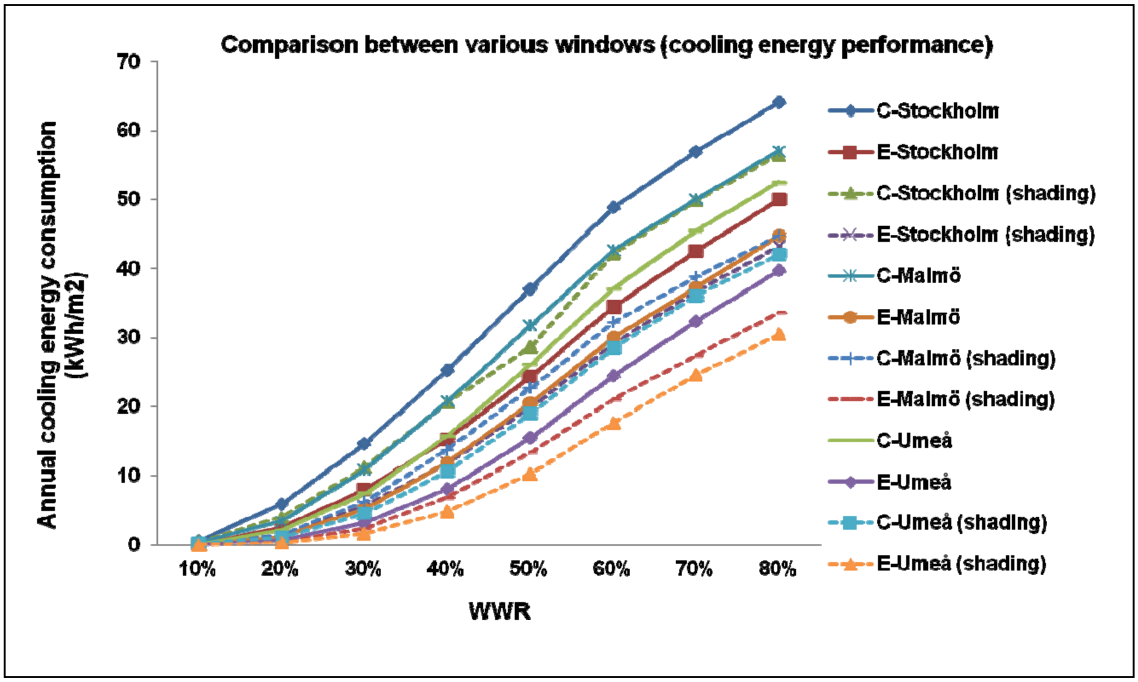

Figure. 8: The comparison of annual cooling energy consumption between various window systems (C: common window; E: energy-efficient window).

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GfK Global Green Index:
Consumers contribution to Energy Efficiency

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1. Background of the GfK Global Green Index

Recent disasters like in Fukushima brought the environmental awareness back in the focus of many consumers during the last two years. Especially in Germany, this topic is very present in the media and discussed almost daily in current energy-political debates. Besides, the change of social paradigms and the global dynamism caused consumers to change their attitudes towards the sustainability of their own consumption. Hence, the long-term and valid measurement of the environmental awareness is a key and trendsetting task.

This development prompted GfK, one of the biggest market research companies, with more than 11,000 employees in more than 100 countries worldwide, to initiate the GfK Global Green Index in August 2011, measuring the environment-conscious being of Germans in central dimensions. In addition to general settings, it is also lighting up whether and in which magnitude consumers are ready to bear arising expenses for environment-conscious behavior. Besides, the profile investigation serves for the explanation of setting changes with consumer groups, social environments or environments on lasting and green subjects. Through quarterly evaluations with N = 2,000 interviews in each wave, GfK was able to build up a valid database reflecting developments.

Amongst others, the GfK Global Green Index provides answers to the following questions:

- Is sustainability relevant for consumers in the long term?
- Which criteria matter for certain consumer segments, life styles, etc.?
- How do the attitudes to sustainability and green subjects change over time?
- Which external events are responsible for these changes?
- Which role do phenomena like the demographic change play for society?
- Which differences are there between certain cultural rooms, for example, India versus Germany versus Russia?

Since 2013, the GfK Global Green Index has been expanded to relevant markets across Europe, Asia and America. Currently, the following countries are components of the research:

- Germany
- Australia
- Brazil
- France
- India
- Italy
- Austria
- Poland
- Russia
- Sweden
- Spain
- Turkey
- UK
- USA

2. Construction and contents of the GfK Global Green Index

A base of the GfK Global Green Index were extensive validity tests of approx. 60 statements on the subject of Sustainability and Environment-conscious being in Germany.
In two successional representative studies, each with a sample of n=2,000, respondents were asked to answer whether they agree or disagree to the mentioned criteria by using a 4-stage scale. In cooperation with GfK association, a factor analysis provided the means to identify the most expressive single criteria as representative variables for the formation of the GfK Global Green Index. Besides, the resultant factor loads of the analysis were used for the weighting of the single criteria.
After the extensive choice procedure to the inquiry of the relevant statements which form the base of the GfK Global Green index the respective sub-indices or the overall index were formed in a two-stage process.

2.1 Stage 1: Construction of sub-indices

In the first stage, suitable sub-indices were formed out of well-chosen statements for each case.

- Energy Efficiency
- Energy Supply
- Consumption & Production
- Mobility
- Tourism
- Waste/Recycling/disposal
- Environmental Protection & Resources

Altogether, there are seven sub-indices which describe the Environment-conscious being extensively: Before the sub-indices could be formed, nevertheless, the answers from the single statements had to be made operationalizable. This was accomplished by generating so-called relative contraposition balances, a procedure which already has been used for a long time for the generation of index values across many studies of the GfK. Following an example in order to visualize the approach:

Question / Statement: "When shopping, I pay special attention to certified organic and seals of quality.

Response Options:

- Totally agree (A)
- Rather agree (B)
- Rather disagree (C)
- Totally disagree (D)
- Does not apply to me (E)
- Do not know (F)

Relative Saldo RS: $RS = \left(\frac{A+0,5*B-0,5*C-D}{A+0,5*B+0,5*C+D} + 1\right)*100$

From the statements in each case so-called contraposition balances are formed. The part of respondents which do not agree is drawn off i.e. from the percentage of those which agree to the respective statement. Besides, the answer categories B and C (agrees rather, does not agree rather) are weighted only by half compared to the answers A and B („agrees completely", „does not agree at all").

In another step, a so-called relative saldo (RS) is formed, while the absolute balance is divided by the sum of the percentage of the "Agreement" and "Disagreement" (again weighted). Finally, a value of 100 is added. As a result these relative balances of statements show a value range from 0 to 200. Consequently, the positive and negative answers are balanced at a score of 100.

Each single statement is then summarized to the respective sub-index in the next step. Nevertheless, the relative balances do not count same-weighted into the index (33% with three statements or 50% with two statements).

The factor loadings from the previous factor analysis, which have been the basis for the selection of incoming statements, are used for weighting. As a result, the respective sub-index is compiled, also showing a value range from 0 to 200.

2.2 Stage 2: Construction of the overall index out of the sub-indices

Finally, the overall index (GfK Global Green Index) is formed from seven sub-indices. In this case, the factor loads are also pulled up again for the weighting of the respective sub-indices. Specifically the sum of the factor loads of the respective sub-index is authoritative as a weighting size. This implies that sub-indices, which consist of three statements, count with a higher weight.

3. What is special about the GfK Global Green Index

From the experience with a significant number of long-term consumer studies, GfK learned that asking for attitudes in areas that are in principle positive for the society, but may imply personal efforts to the respondents is a challenging task to get valid and accepted information about the actual expected behavior. Although there are existing experiments to defuse this problem as a pseudo-inconsistency [1], the prevailing opinion seems to support the theory of an existing gap. To shrink the interval between expressed future behavioral intentions and the actual behavior, GfK decided to face respondents with consequences, asking for most items within the dimensions for the GfK Global Green Index. The costs to pay for energy saving may serve as an example. Here we would like to know, to what extend consumers are attracted to use energy efficient devices. The measurements of the corresponding statement “I personally would only pay costs for energy saving e.g. with the purchase of energy efficient devices, if this is economically viable for me” showed that there is a wide variety of results among socio-demographic subgroups as gender or age, which could not be found in a control group survey with a similar statement without the monetary consequence. From GfK’s point of view, this leads to more honest answers as the given consequences reflect the personal reality of the respondents even more.

4. The subject energy efficiency in the GfK Global Green Index

According to company specifications of Siemens, 40 percent of the worldwide energy consumption is caused by the building inventory. By a huge number of measures which reach from the intelligent house automation, through efficient lighting system to measures in the insulation and heating area, a very big energy saving potential comes up here. According to Siemens, saving effects can be reached with modern and intelligent applications and reduce power consumption in the area of household appliances by more than 50% compared with the 1990s [2].

Due to the commonly accepted importance of energy efficiency in private households, the GfK Global Green Index covers this topic by six criteria measuring the attitudes of consumers towards their own energy saving behavior over time. The items currently used are assigned to the sub-indices “consumption and production“ as well as "energy-efficient":

Sub-index „Consumption & Production“:

- When buying large and small electrical devices I make sure that they have a low energy consumption even though they may be more expensive than other devices.

Sub-index „Energy Efficiency“

- I personally would only pay costs for energy saving e.g. with the purchase of energy efficient devices, if this is economically viable for me.
- I personally would only pay costs for energy efficiency measures e.g. insulation, if this is economically viable for me.
- When purchasing energy saving products, the most important thing for me is environmental protection and not saving money.
- All property owners should be obliged to carry out energy saving renovation measures as you can save a great deal of energy if such measures have been carried out in a building.
- I would be willing to spend more on energy efficient products in the future to lower my energy consumption.

To be able to show a profound and holistic picture of the dimension “Energy Efficiency”, the GfK Clobal Green Index also frequently contains questions to seasonal matters. In March 2012, the Global Green Index measured the prohibition of conventional bulbs and the reaction of consumers to this. In the other dimensions similar key topics were conducted over time as well.

5. Attitudes to energy efficiency in Germany

Looking at the results in Germany, it is clear, that the current willingness to realize energy efficiency measures depends heavily on the resulting additional costs and the expected benefit for consumers.

Although nearly 90% of German consumers specify to pay attention on energy consumption when buying major and electrical appliances, only 80% would spend extra money on energy saving appliances e.g. energy efficiency if it is economically worthwhile.

The same applies to other energy efficiency measures such as insulation in their own house. Hereby 8 out of 10 persons were concerned that cost aspects are clearly ahead of the environmental aspect which could be realized by the measures, as well. Consequently, only relatively few consumers are for legal regulations in this area. Only 15% fully agree with it e.g. that for homeowners energy-saving renovations should be made mandatory by law. One third does not tend to the criterion; almost 20% oppose such a scheme even completely. For the future of energy-saving products, it begins to show a slightly positive attitude related to the willingness of investments. After all, nearly 2/3 of the Germans are certain to pay more for energy efficient appliances and products in order to reduce their own energy consumption in the future.

As mentioned before, in addition to the criteria evaluated in each survey wave, the Global Green Index regularly includes special measurements usually reflecting current issues treated in the media or policy issues.

In March 2012, the Global Green Index evaluated the prohibition of conventional bulbs in accordance with the 2009 EU Regulation [3] and the reaction of consumers to this.

Since September 2011, there were conventional bulbs (with filament) only with less than 60 watts of power to buy in German shops. However, old remnants of more than 60 watts of power could be sold off. From perspective of the GfK, the question arose, how consumers would react, if they would be in need of new bulbs with 60 watts of power or more?

According to GfK Global Green Index at this time, more than 40% of the Germans had old replacement bulbs with 60 watts of power or more in their households, which could be used in case of a required exchange. Only 60% would demand firstly to entire new light bulbs. 17% of the Germans said they exchange their old conventional bulbs again for the remnants of the conventional bulbs in stores. However, the advertising campaign by lamp manufacturers for the new generations of energy-saving light bulbs seemed to have reached consumers. Almost two-thirds would move to energy-saving bulbs to replace the old light bulbs at this time. 1 out of 5 persons would have used halogen bulbs instead.

A similarly interesting and in Germany currently highly topical issue is the debate over state accelerated energy policy and funding of it. In 2012, the increase of the allocation for “facilitating renewable energy” short EEG-allocation, increased by almost 50% on 5.277 Cent per kilowatt hour and added to the electricity price, as it was announced by the four German transmission system operators [4].

In consequence, this meant an increase in the cost of electricity for consumers raised the question, whether the importance of energy efficiency issues increased for consumers. It showed that the willingness of spending more money for energy efficient products to decrease the own energy consumption is higher than ever before – after all, 65% of Germans want to do this in future. Furthermore, a group of Germans is also willing to undertake even more measures to reduce their own energy needs at home. Almost 1 in 5 are currently thinking about consultancy to reduce energy consumption and do not hesitate to pay additional costs. Just as many Germans are going to purchase apparatuses for the control of power consumption, so called meter readers, to identify inefficient energy usage

17% of the Germans want to use the possibilities for the continuous monitoring and better control of the own power consumption through smart meters in the future as soon as possible. The overwhelming majority of consumers willing to improve their personal consumption shows that consciousness for "energy-saving" arrived. More than 80% will try to decrease the power consumption by paying more attention to the fact that for example televisions or computers are not running on stand-by mode.

The described measures above may not hide the fact that the Germans are facing the issue of “energy efficiency at home” still in a reluctant way. Once-only, higher costs for energy efficient appliances still seem to represent a very high barrier for a majority of consumers. In October 2012,

the associated index value for the field of energy efficiency reached with 34 out of a maximum of 200 points a very low value. A comparison over time also shows that since the first survey in August 2011 (Index value: 36), even a slightly negative trend is established.
This development is, in the context of the ongoing Euro Crisis and the growing uncertainty about the development of the labor market, quite understandable. At the same time, the question turns out if this rather reserved attitude towards specific energy efficiency measures affects all German citizens alike or if there are identified differences between certain groups.
To find an answer for this and to provide a deeper insight into the issue, some results will be considered in the following examples concerning the concept of biological lifestyles. It is possible to segment the German population according to their phase of life and socio-economic situation and to identify existing differences through this concept.
The life-worlds approach thus differs significantly from conventional types and outlines. It offers a new and substantiated view by an extensive research perspective on the population structure. The following table provides an overview with a rough description of the 15 biographical lifestyles and their summary to five lifestyles [5]:

Summary	Description
Youth/ Students	**Youth**: The development of the social. Adaptation and protest. The youth cultures.
	Students: The future elite. Big goals, lack of funds
Upper class (Top)	**Young Top**: The best chance for self-development. Activity and the pursuit of success.
	Middle Age Top: The ruling elites. Power and privilege.
	Housewives Top: The world of women at senior levels. Self-realization.
Middle Class (Average)	**Young Average**: The young middle class. On the way to success
	Middle Age Average: The established. Protecting and expanding the achievements.
	Housewives Average: The womens´ world of the middle class. Individuality and duty.
Simple life situation (Low)	**Men - Low:** Men in easy circumstances. Concreteness in work and leisure. The traditional masculinity.
	Women – Low: Women in easy circumstances. Concreteness in work and leisure. The traditional female role.
Retirement	**Older Men, Middle class:** The world of the post-professional phase. The new freedoms and activities.
	Older women, Middle class: The life world of older women. The new self-awareness and attention to the emotional.
	Older, working-class men: The world of the post-professional phase. The new freedoms and activities.
	Older, working-class women: The world of older women. The new self-awareness and attention to the emotional.
	Single Mature (own household): The self-determined life in old age.

The lifestyles are divided into two basic dimensions. On the first hand, there are stages of life, which can be divided into three main phases:

- School and vocational training
- Gainful employment or unpaid household work
- Retirement

On the second hand, the lifestyles are based on the dimension of the individual socio-economic situations. It expands the vitas into hierarchical levels which unfold especially in the period of employment. These lifestyles during the employment stage are differentiated into three levels (Top, mid and simple life situations). In addition, distinction is made according to status passages (Younger and middle age life forms).

To avoid becoming too complex with the following explanation, the original 15 biographical lifestyles are summarized in 5 lifestyles (Youth/ Students, Upper Class, Middle Class, Simple life situation, Retirement) for the Global Green Index.

In consideration of attitudes about energy at home and energy efficiency, there are some clear differences in the individual lifestyles. It is conspicuous that teenagers / students have a more sustainable attitude than the other lifestyles on the issue. With an index value of 63 points (out of a maximum of 200 points) in October 2012, this group even has a clear improvement potential, but it achieves nearly twice as high values as the average of the remaining segments.

In the socially deprived groups, the index values are at their lowest level. Retired working-class members exhibit, for example, at a value of only 21 points form clearly the weakest of the summarized lifestyles. The issue of sustainability seems to play a secondary importance, if the wallet is hard-pressed for money. In reverse, the better-off lifestyles (Upper Class, Older Single and Older Middle Class) are at the top of the leaderboard in the third quarter of 2012.

Apart from the individual phases of life, there are other criteria which play an important role. For example, the willingness to spend more money for energy efficient products in the future in the lower-income East Germany is clearly lower pronounced than in the western part of Germany. This "sacrifice money" also seems to be notably an issue of the level of education.

While only about half of the less educated population groups plan higher investments for energy efficient products in the future, there are nearly three quarters within the group of people with high school or college degree.

6. Preview on international results

The GfK Global Green Index has expanded its coverage on an international scale since 2013, now allowing a comparison on a global level. First results are already available and briefly outlined in the following. First of all, it is important to note that the issue of "Energy Efficiency" appears with an index value of 34 points (out of a maximum of 200 points) in Germany. It seems to be less important than in most other European countries considering the current study. However, in the interpretation of the values one must note, that people in different countries also have a different understanding of their own behavior towards actions for energy saving. Therefore a unilateral reflection of the index values is wrong. It rather requires a classification of the level of energy savings in each country to relate it to the index values.

The table below shows the various countries gathered in this research and the respective corresponding index value.

Country of interest	**Index-Value „Energy Efficiency“**
Russia	57,2
Austria	48,4
Poland	43,2
Italy	42,7
Spain	40,3
France	38,5
Sweden	35,4
Germany	**34**
UK	31,7
Brazil	37,7
US	29,4
Turkey	29,0
Australia	24,1
India	8,4

The total index values in all countries are relatively low across all countries. Compared to most European countries, residents of the US and Australia seem to have much lower interests in energy efficiency measures carried out for environmental reasons. This seems to be due to various life

circumstances historically grown in both countries, where resources such as fuel and energy for a long time were declared endless available.
The interesting point is that the statements of the Global Green Index reflect both a consideration of the present and the future expectations of the inhabitants of a country. While today 65% of Germans are willing to spend more money for energy efficient products in the future, more than 80% residents in the United States were willing to be more energy-conscious. In Australia, the value reaches almost 90%. This shows that the issue has already become very important in these countries.
The described results represent a sample of the current GfK Global Green Index study of GfK SE and the GfK Association. In Germany, the study has been conducted since 2011. In the international context, the interviews take place since 2013. In some of the countries listed on page three, the results are not yet available.

7. Summary

Initiated in 2011, the GfK Global Green Index is an instrument to measure environmental awareness of consumers in Germany and since 2013 on an international level. The awareness of energy efficiency will be pressed ahead as part of the ongoing debate about the turnaround in energy policy in Germany. Here, the people become more sensitive and increasingly more informed about possible savings. The willingness to invest in energy-saving domestic appliances increases. Nevertheless, in Germany as well as in Anglo-Saxon countries a large growth potential can still be observed. This has to be operated through targeted programs of companies in these industrial needs. For Germany the GfK Global Green Index already offers detailed information on which action consumers give the first priority.

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Are people continuing to save electricity?: Consistency of measures and behavior changes in the electricity crisis in Japan

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Abstract

Due to the Great East Japan Earthquake and the subsequent reduction in the operating rate of nuclear power plants, there have been continued shortages of electric power, particular in the summer months in Japan. In the summer of 2011, electricity saving with a target of 15% was carried out in the service areas of Tokyo Electric Power Company and Tohoku Electric Power Company. In the summer of 2012, efforts were made to save the electricity throughout Japan, particularly with a 10% target in the Kansai Electric Power Company's service area. This study aims to examine changes from 2011 to 2012 in terms of the electricity conservation rate, implementation rates of measures to save electricity, and awareness of electricity conservation. We conduct a follow-up survey of about 1500 households in Tokyo who participated in our previous survey, and a new survey was conducted to about 1100 households in Kansai. Excluding the effects of weather, the electricity consumption during the months of July-September 2012 was lower by an average of 11% than the 2010 level in Tokyo, and by an average of 9% in Kansai. The implementation rate was slightly lower than the level of the previous year in Tokyo. In Kansai, the implementation rate increased in 2012, although not to the extent of Tokyo households in the summer of 2011. In Tokyo, normative incentive and informational incentive became weaker, while economic incentive was stronger partly stimulated by the electricity rate increases in September 2012.

1. Introduction

Shortly after the Great East Japan Earthquake occurred in March 2011, apprehension arose regarding electricity shortages depending on some regions and seasons in Japan.

In the summer of 2011, a large-scale demand restraint was requested, i.e., a target of 15% peak electricity demand reduction was set in the service areas of the Tokyo Electric Power Company (TEPCO) and Tohoku Electric Power Company, and the legal restriction of electricity use was issued on large-lot users. Households were encouraged via the mass media and other means to conserve electricity [1][2]. Electricity users in the service area of the Kansai Electric Power Company (KEPCO) were also requested to reduce electricity consumption by at least 10%, and those in other service areas were asked to conserve electricity as much as possible without negatively affecting people's lives and economic activities. Thanks to massive electricity-saving efforts by firms and households [3][4], power outages were avoided. The government reviewed that households in the TEPCO service area reduced consumption by 11% and those in the KEPCO service area by 4% in terms of the peak demand after adjusting for weather conditions [5].

After the summer of 2011, electricity shortages became a nationwide problem, because of delays in the restarting of nuclear power plants that had been suspended due to regular inspections. Especially, the demand and supply situation in the summer of 2012 was expected to be severe again. Thus in June of 2012, the government decided to restart the KEPCO's Oi nuclear plants. The acquired prospect of an increase in power supply led to a gradual easing in the targets of peak demand reduction, and in the end, the targets for summer 2012 were as follows: Kansai and Kyushu - 10% or more, Hokkaido - 7% or more, Shikoku - 5% or more, and other regions had no numerical targets. The actual situation of demand and supply remained stable due to the continuation of the large-scale electricity conservation efforts just as made in the previous year [4][6]. It was reported that households in the KEPCO service area reduced its peak demand by 10%, and in the system as a whole, enterprises and households in the TEPCO service area saved 12.7%, and those in the KEPCO service area saved 11.1% during peak demand.

With such efforts as a given, an electricity crisis could be avoided in the summer of 2013; however, close attention needs to be paid to the unexpected decrease in supply capacity, lowering of electricity conservation awareness, and increases in demand accompanying the economic recovery. It is vital to continue to investigate the electricity conservation status, and to learn lessons from the experiences for better energy efficiency policy and programs after supply and demand have been stabilized. It is also necessary to examine the continuity of electricity-saving, just as reviewed in other countries [1].

Accordingly, we carried out a questionnaire-based survey of electricity consumers in order to elaborate the electricity conservation efforts in the household sector during the summers of 2011 and 2012. Firstly, Section 2 sets out an overview of the survey. Sections 3-5 cover the electricity-conservation rates, implementation rates of conservation measures, and changes in conservation awareness. Finally, Section 6 summarizes the key findings.

2. Survey outline

Our previous survey conducted in November of 2011 covered the electricity-conservation status of households that were served by TEPCO ("TOKYO") in the summer of 2011 [3]. For this research, we conducted a fixed point observation of the electricity-conservation situation by a follow-up survey of the respondents of the previous survey. We also attempted to compare results by region, by conducting a new survey of households under KEPCO ("KANSAI") who were faced with high electricity-conservation targets in the summer of 2012. Both surveys were conducted in November of 2012 with respondents participating via the Web, and we used the same questions and lists of answers to those of the previous survey as much as possible for comparison. The numbers of valid respondents were 1,517 for TOKYO and 1,119 for KANSAI, out of 19 million TOKYO customers and 9 million KANSAI customers.

3. Changes in electricity-conservation rates

We analyzed electricity conservation quantitatively by tracking changes in electricity consumed between 2010 and 2012. The electricity-conservation rates discussed in this paper are taken in comparison to electricity consumption (kWh) between July and September 2010. It is noted that the actual numerical targets and results reported by the government are based on the peak electricity (kW).

Figure 1 compares the average amount of electricity consumed by the target households between July and September before adjusting for weather conditions. The electricity consumption in both 2011 and 2012 are far less than the amounts used before the earthquake. Although this is not an accurate comparison since weather influences are included, TOKYO reduced electricity consumption by 15.4% and 17.5% in the summers of 2011 and 2012, respectively, when compared to the summer of 2010. Likewise, KANSAI achieved reductions of 9.9% and 13.6%, which were fairly small compared to statistical data.

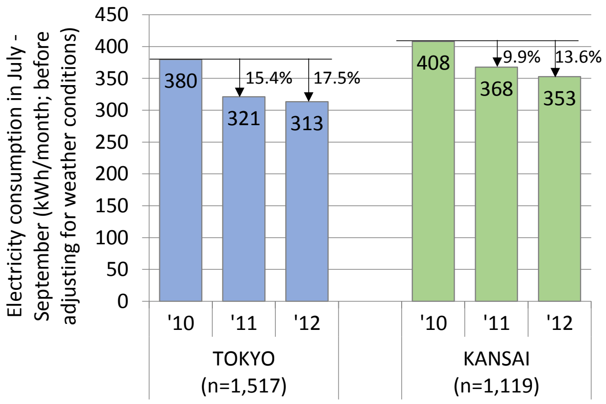

Figure 1. Electricity consumption (before adjusting for weather conditions)

Electricity demand is easily affected by weather conditions. Especially since there was a record heat wave in 2010, it is necessary to remove the meteorological factor in order to study the actual effects of electricity conservation. Thus we adjusted the amount used for each household by standardizing weather conditions in 2010. The adjusted electricity-conservation rates for both regions in Figure 2 were reduced compared to pre-correction figures after correcting for 2010's record heat. TOKYO saved 10.6% in 2011 and 10.9% in 2012, while KANSAI households saved 7.4% in 2011 and 9.2% in 2012.

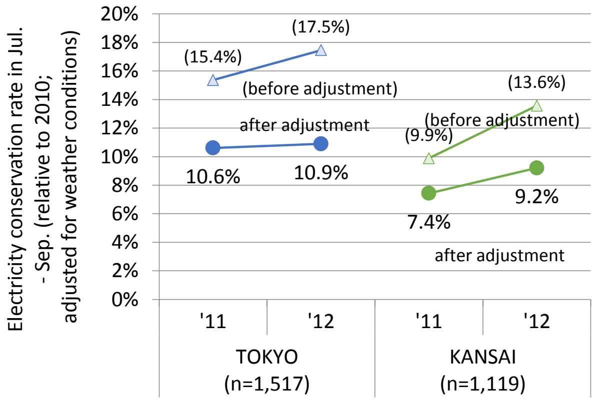

Figure 2. Electricity conservation rate (after adjusting for weather conditions)

The figure above shows that TOKYO conserved almost the same amount of electricity in both 2011 and 2012. A brief look at this result is as follows. Looking at summer electricity consumption intensity trends over the past 10 years shows a slight reduction trend, which is due to the increasing energy-efficiency of air-conditioners. In the year leading up to the summer of 2011 in particular, the number of air-conditioners shipped reached record levels, stimulated by a government support measure for the purchase of energy-efficient appliances (“the Home Appliance Eco-Point System Policy”) and an increase in the electricity-conservation awareness. The effects of these replacement purchases continued into 2012, meaning it is possible that, even though the electricity-conservation rates are the same compared to 2010, the effects by changes in behaviors such as patience and ingenuity might have been lower in value. Specifically, if we take into consideration that, in the previous study, about 15% of the electricity-saving effects in 2011 was due to replacement purchases, it is likely that the electricity-conservation effects based on actions may only reach 80-90% of the previous year.

4. Changes in implementation rates of measures

The changes in electricity consumption indicated in the previous section can also result from factors other than electricity-conservation efforts. What is more fundamentally important is a concrete understanding of the ways in which electricity-conservation measures have changed. This section will therefore cover the changes in the implementation rate of each type of measure.

First, Figure 3 compares the rates of awareness of electricity-conservation for each kind of end-use. Note that, since we did not perform a survey for KANSAI in 2011, data for this period does not exist. Comparison by region and by year shows that TOKYO in 2011 was the highest, while in 2012 it was KANSAI first and TOKYO second. The difference in the types of end-use shows awareness about air-conditioners and lighting as the highest at 70-90%, while awareness about electricity conservation for refrigerators was low at 40-60%.

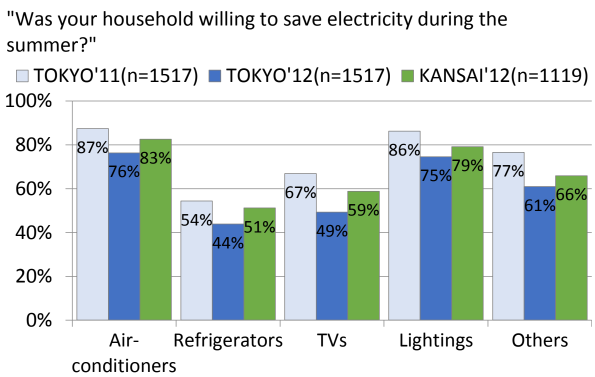

Figure 3. Awareness of electricity conservation for each end use

Next, Figure 4 compares the implementation rates of the main electricity-conservation measures that had high effects overall, taking into consideration their implementation rates and their electricity conservation effects when implemented. Here, we took the top 10 measures derived from the previous survey for TOKYO that were most effective overall and then compared the implementation rates for each region and each year. The overall trend showed that implementation rates were highest for TOKYO in 2011 and fairly high for KANSAI in 2012. TOKYO in 2012 and KANSAI in 2011 often switched relative places depending on the conservation measure. A look at the change in the implementation rates of measures for TOKYO shows that continuous actions such as reducing the time of air conditioner use and lighting use experienced a fairly large decline in the implementation rate.

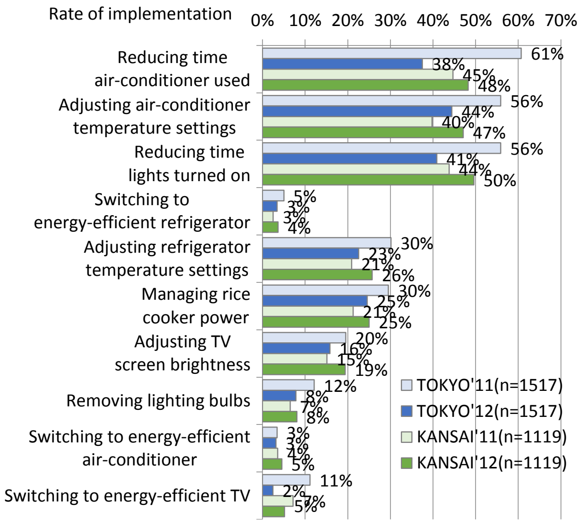

Figure 4. Main electricity conservation measures with high overall effects

5. Changes in electricity-conservation awareness

This section paid close attention to electricity-conservation awareness, especially on its changes from 2011 to 2012. This section first takes a look at the overall trends, then examines the changes in the six awareness factors we had proposed in our 2011 study [3]. These factors are: Normative incentives, Informational incentives, Economic incentives, Patience, Ingenuity, and Continuity. Our findings in this section is summarized that, among the six awareness factors in the TOKYO samples, only Economic incentives saw a rise in 2012, while the other five awareness factors weakened. This transition is contrasted with that in KANSAI, where all awareness factors strengthened in 2012 than in 2011, due to a tighter power supply situation and more aggressive power conservation campaign experienced there. These observations are evidenced with the responses to the respective questions in the survey, which we depict one after the other in the following. We begin with the awareness structure discovered in our last study.

Figures 5a and 5b show the revealed structure using the six awareness factors. The quantitative data for statistical analysis was obtained through questions with 5 levels of evaluation, ranging from "Agree" to "Disagree." In Figure 5a, latent variables (in ovals) are connected with questions (in squares) that are used to quantify these latent variables. For example, "Normative incentives" variable is quantified on the basis of the four questions on the northwest of that oval. To simplify this figure, we present an excerpt of this result as Figure 5b, which only shows the latent variables and estimated influences among them. The influences can be either positive (+) or negative (-), and the widths of the arrows represent the strength of such influences. It is inferred that, for example, "Informational incentives" strengthen "Ingenuity" on one hand, while weaken "Patience" on the other, both resulting in increased "Continuity". On the basis of these results, we followed up on the questions with the aim of conducting a fixed point observation in order to elaborate how the feelings of the respondents had changed.

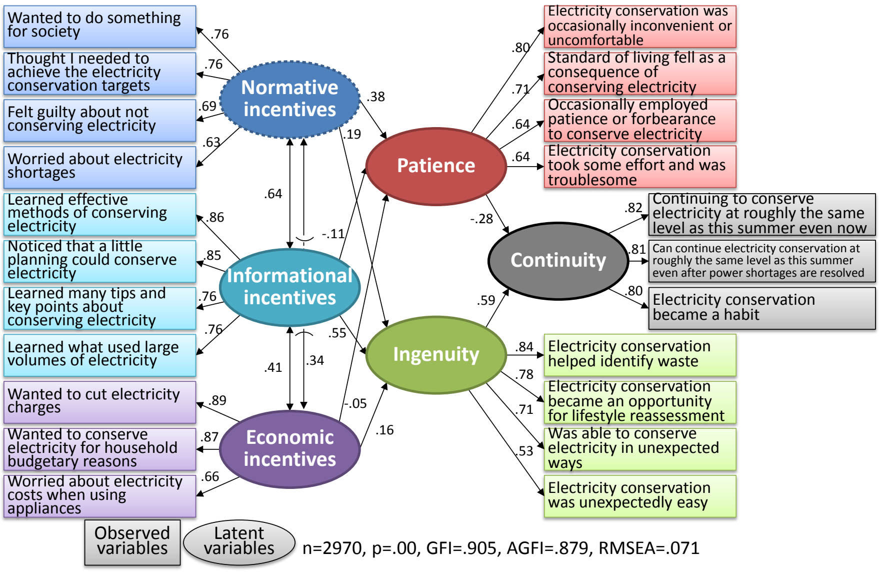

Figure 5a. Incentives, types of efforts and continuity (Source: Nishio and Ofuji, 2012)

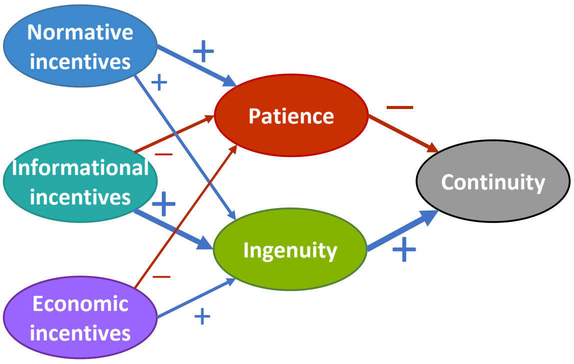

Figure 5b. Incentives, types of efforts and continuity [Excerpt] (Source: *ibid.*)

Overall trends

Figure 6 shows impressions gained by comparing the electricity-conservation situation in 2012 to that of the previous summer. Regarding the three incentives, we took the questions that were statistically extracted as representative factors in the previous survey and scored the changes on 5 levels. An average positive score represents a strengthening over the previous year while a negative score represents a weakening.

According to the figure, economic incentives grew stronger while normative and informational incentives weakened in TOKYO. As a matter of fact, electricity tariffs were increased in September 2012 in the service area of TEPCO. As we concluded in the previous study, the weakening of electricity-conservation efforts involving patience is larger than that of those involving ingenuity. As a result, proactive efforts for electricity conservation became also slightly weaker.

The scores for KANSAI became higher than the previous year's scores for all items. Economic incentives were higher than for TOKYO; however, a direct comparison should be avoided, because they are linked to the degree of effort put into electricity-conservation (as explained later).

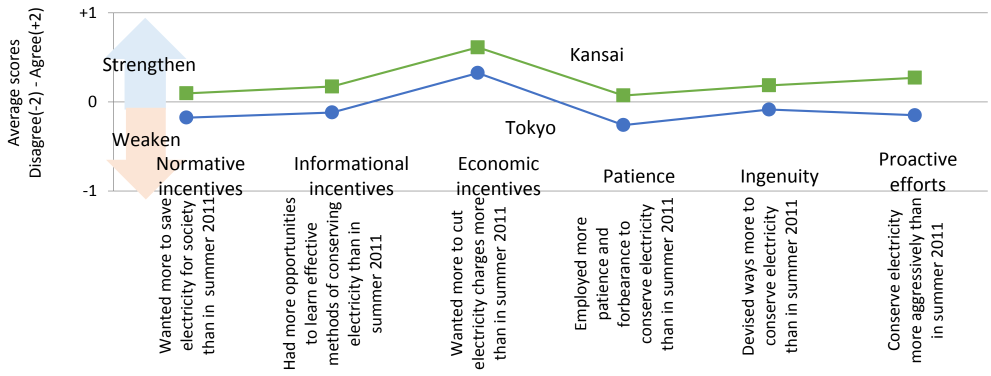

Figure 6. Changes in electricity conservation awareness

Trends in electricity-conservation awareness

For the items being scored on 5 levels for the fixed point observation, we compared the answers at each semantic group.

Figure 7 shows the four items that represent normative incentives. Overall, there were many answers of "Agree" and "Somewhat agree" for TOKYO in 2011. Opinions such as "Worried about electricity shortages" and "Wanted to do something for society" were especially strong. In 2012 however, those normative incentives weakened. KANSAI scored slightly higher than TOKYO ones in that year.

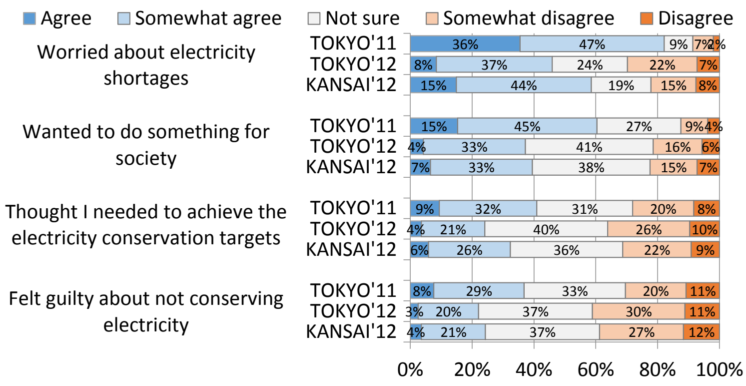

Figure 7. Normative incentives

From figure 8, it can be seen that receiving information was an important motivation for conservation for TOKYO in 2011. There are no great differences between TOKYO and KANSAI in 2012, but KANSAI tended to be slightly higher. As can be seen above, there are many common characteristics between normative and informational incentives.

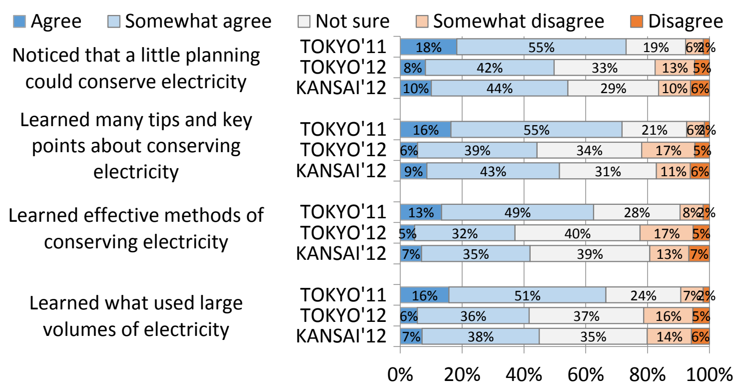

Figure 8. Informational incentives

Figure 9 shows that, overall, "Agree" and "Somewhat agree" answers dominated. While "Agree" answers slightly decreased in TOKYO 2012, it is hard to draw conclusions from the figure about the magnitude of economic factors as main incentives for the height in awareness, since in some cases the motivation to save money on electricity charges is actually stimulated by increased electricity-conservation awareness. In fact, it can be seen from figure 6, which allows changes to be directly observed, that economic incentives were higher in TOKYO 2012. Interpreting these results comprehensively suggests that the level of electricity-conservation awareness decreased for TOKYO from 2011 to 2012 when compared to the level of the previous year, but that the increase in electricity charges led to economic incentives becoming stronger.

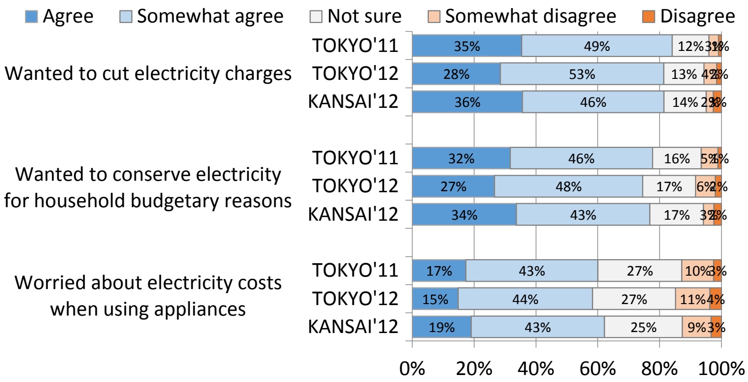

Figure 9. Economic incentives

Figure 10 shows that the tendency towards electricity conservation by patience was strongest in TOKYO in 2011. More than half of the respondents reported that they "occasionally employed self-restraint and forbearance" and that it was “occasionally inconvenient or uncomfortable." KANSAI had a slightly stronger tendency towards patience than TOKYO in 2012.

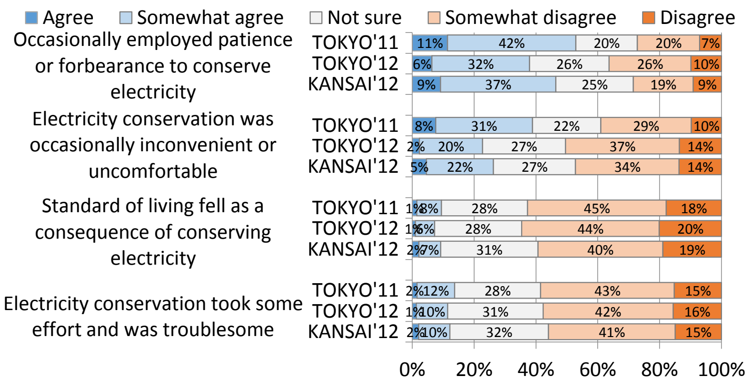

Figure 10. Patience

As shown in Figure 11, TOKYO in 2011 had a fairly large number of positive answers in response to questions related to the electricity conservation by ingenuity in 2011. The degree of ingenuity reduced slightly for TOKYO in 2012. There was not a lot of difference between TOKYO and KANSAI in 2012.

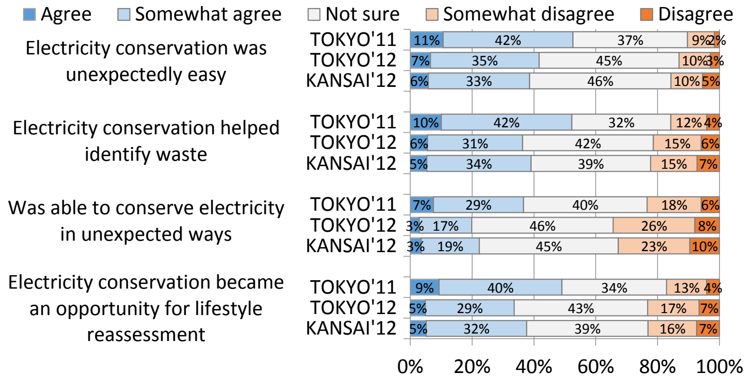

Figure 11. Ingenuity

Trends shown from answers such as "attempted electricity conservation proactively" and "was able to achieve generate electricity conservation effects" show that the level of positive attitude was highest in TOKYO in 2011 and weakened in 2012, while KANSAI in 2012 grew closer to TOKYO in 2011 (Figure 12).

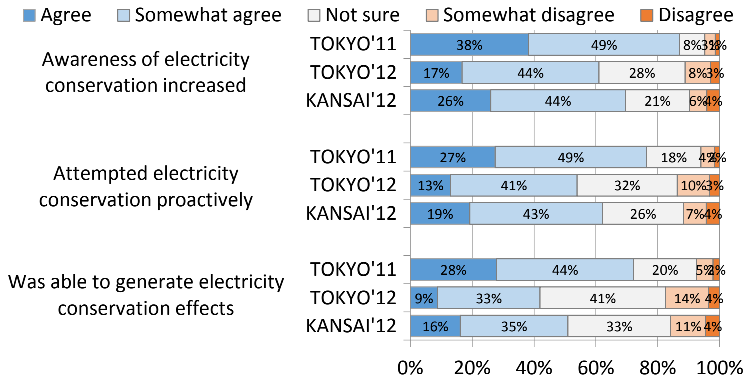

Figure 12. Proactive effort to conserve electricity

Intention to continue electricity conservation

Figure 13 shows a comparison of the results for the 5-level evaluation of the intention to continue the electricity conservation. The research hypothesis was that the intention to continue would differ in accordance with the severity of power shortages and the level of electricity conservation efforts. However, based on this comparison, even though there were many positive answers from TOKYO in 2011, there was almost no clear difference overall.

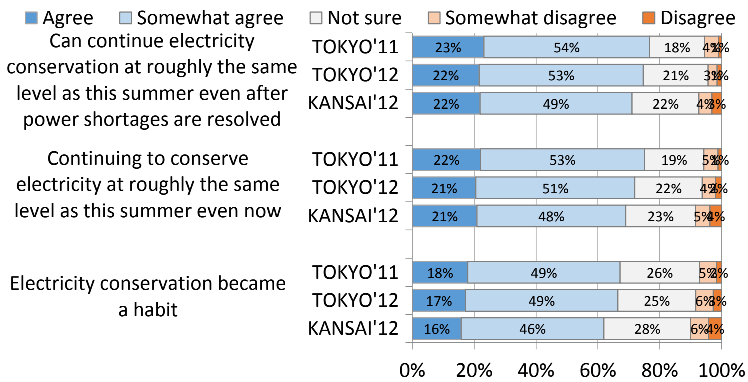

Figure 13. Intention to continue electricity conservation

In light of this, the question rises as to how to interpret these answers regarding the intention to continue. In order to answer this, we used the TOKYO household data that allows for fixed point observation. First, we took the data from 2011 regarding positivity towards and desire to continue conservation. Then, we took the data from 2012 regarding the positivity towards conservation and we studied the changes. Specifically, the question that represented positivity was "attempted electricity conservation proactively," while the question that represented the intention to continue was "Can continue electricity conservation at roughly the same level as this summer even after power shortages are resolved." While both questions were originally graded on 5 levels, "Agree" was tallied as "High," "Somewhat agree" as "Medium" while "Not sure," "Somewhat disagree" and "Disagree" were tallied as "Low", in the following.

Figure 14 shows a clear relation between the proactive effort and intention to continue in 2011 and the proactive effort in 2012. Firstly, the people who gave high answers for positivity in 2011 also gave high answers for positivity in 2012. Secondly, the people who gave positive answers regarding continuation also indicated high positivity the following year. However, when it comes to the question whether those who initially expected to continue "roughly the same amount" of conservation were actually able to do so, there were a lot of people who resulted in a regression in comparison to the positivity of the previous year. This implies that it is possible to guess the kinds of changes that will occur on the effort level by asking people about their plans to continue, however, it should be recognized that fairly positive answers tend to be obtained from the awareness survey compared to the actual situation.

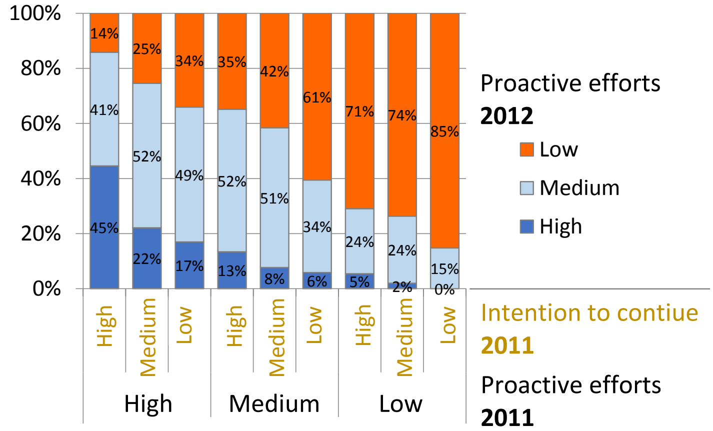

Figure 14. Proactive effort and intention to continue electricity conservation

6. Conclusions

Key findings

In this study we examined changes from 2011 to 2012 in terms of the electricity conservation rate, implementation rates of measures to save electricity, and awareness of electricity conservation in the service areas of Tokyo Electric Power Company (TEPCO) and Kansai Electric Power Company (KEPCO), the two biggest power companies in Japan. The key findings from this study were the following:

- After adjusting for the weather conditions, the electricity consumption (kWh) during the months of July-September 2012 by the surveyed households declined by an average of 11% from the 2010 level in Tokyo, and by an average of 9% in Kansai. For households in Tokyo, electricity consumption was almost the same level of the summer of 2011, while for Kansai Electric households, there was an increase in the reduction rate. In Tokyo, the reduction by behavior changes became fairly small, whereas there was a continuing effect of switching to energy-efficient products, and thus it is conjectured that the same level of reduction continued.
- On the whole, electricity conservation continued in various appliances such as air-conditioners and lighting. However, the implementation rate in Tokyo was slightly lower than the level of the previous year. In Kansai, the implementation rate increased in 2012, although not to the extent of households in Tokyo in the summer of 2011 when there were serious concerns about a short supply of electricity.
- The similar results were also indicated in proactive behaviors to save the electricity. In Tokyo, normative incentive and informational incentive became weaker, while economic incentive was

stronger partly stimulated by the electricity rate increases in September 2012. A weakening of efforts was observed, primarily electricity-saving by refraining from use.

Discussions

Will electricity conservation continue or not?

In the last study, we stated that "While social norms played an important role in raising consciousness of electricity conservation, they tended to lead to electricity conservation through self-control on air-conditioning, lighting, and other uses and in some aspects these effects are difficult to continue." This tendency was confirmed through this follow-up research. Nevertheless, in general, many electricity conservation activities were continued, which was also observed in the high reduction rate in terms of electricity consumption. It goes without saying that such efforts contribute to the stabilization of supply and demand balance. On the other hand, the conservation awareness has not dropped significantly and large numbers of people are still striving to conserve electricity while exercising self-restraint and forbearing. This implies that there is the continued need to keep a close watch on electricity-conservation awareness and actions.

How to encourage action

After the earthquake, the awareness of electricity conservation spread widely through society. While advances in the replacement purchase of energy-efficient products played a part, a large part of the savings was driven by changes in behaviors, such as using energy-efficient settings and changing the way air-conditioners and lights are used. Some respondents said they were motivated not solely by a desire to save money but also by a desire to do something for society. Based on a deeper understanding of the importance of easily understandable information and of behavioral principles that social norms motive people in no small part, it is essential to keep improving information provisions on electricity conservation tips and electricity consumption feedbacks.

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Cold Wash – Do Prejudices Impede High Energy Savings?

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Abstract

The main share of washing machine electricity consumption is used for heating cold tap water to 30°C, 40°C, 60°C or even 90°/95°C. Washing at lower temperatures (max. 20°C) uses 70% less electricity compared to a 60°C cycle. The EU Eco-design regulation accounts for the high energy savings potential and requires that «from 1 December 2013 household washing machines shall offer to end-users a cycle at 20°C».

Appropriate washing machines and detergents for «cold wash» are already available to residential consumers. Therefore this paper will first give an overview on best-performing washing machines (Best Available Technology BAT) available on the European market according to www.topten.eu. Detergents designed for «cold wash» are available as well. Washing performance at low temperatures is crucial. Based on the experiences of a Swiss detergent manufacturer, it can be said that in cases of slightly and normally soiled laundry «cold wash» is effective.

In practice, it is consumers who opt for the washing temperature and thus determine by their behaviour the amount of energy that can be saved. Although for slightly and normally soiled laundry the washing performance at low wash temperatures is absolutely perfect, most consumers still wash at higher temperatures. Prejudices, which impede high energy savings, will be discussed in the following pages.

The paper also illustrates the experience of a large Swiss retailer, who promoted «cold wash» in 2008 as one of the first through a large Swiss-wide marketing campaign.

We conclude with recommendations for various stakeholders such as EU policies, producers, retailers, NGOs, science and test institutes, how to strengthen the implementation of «cold wash».

Introduction

The washing of clothes and textiles is part of our everyday routine. But by using energy and water it puts a strain on our environment. Consumers have the power! By making a conscious decision to change their washing habits, they can generate a profound impact on the environment and costs, simply by choosing a lower washing temperature or by adding the appropriate dosage of detergent. It may be worthwhile to rethink the everyday routine, because with low washing temperatures, up to 70% electricity can be saved.

This tremendous energy and CO_2 savings potential can – concerning washing – through no other measure be reached so easily. This savings potential, however, lies idle. From the point of view of the authors it is important to take up the issue of «cold wash» EU-wide and to push its implementation.

The aim of this article is to give an overview of the subject and to discuss the status of literature, the popularity of «cold wash» in and outside Europe, the savings potential, the availability of energy-efficient washing machines and of detergents, which are also effective at low washing temperatures, prejudices of consumers against «cold wash» and conclusions of a «cold wash»-campaign carried out in Switzerland. Based on this, recommendations will be derived, how the issue «cold wash» could be pushed and promoted across the EU.

Status of Literature

The topic «washing» has been researched extensively in the context of the Eco-design preparatory study Lot 14 [1]. The developments of washing machines in the EU are regularly analyzed by Paolo Bertoldi and his team [2], [3]. For many years the topic «washing» has been also intensively studied by Prof. Rainer Stamminger and his team [4], including user behaviour (e.g. [5]). A representative and often-cited study on «washing behaviour in Germany» was carried out on behalf of the Energy Efficiency Initiative (Berlin) [6].

Specifically on the topic of «cold wash» there is, at least in German speaking Europe, little scientific literature. An often-cited study was prepared by the Oeko-Institut (Germany) [7].

It is obvious that the washing performance at low washing temperatures is crucial. There are only few published tests on the washing performance of detergents at 15°/20°C (e.g. 2008 [8], 2010 [9], 2012 [10], 2013 [11]). However, these tests focus primarily on how well stubborn stains are removed at low washing temperatures. Their validity, therefore, is limited because the present article is focused on the wash performance for slightly and normally soiled laundry, which is the normal case. Additionally, formulations of detergents have changed in the meantime and some products are no longer available.

Source of numerous contributions on the topic of «cold wash», which sometimes reference some of the above mentioned studies and tests, is the internet (e.g. The German Federal Environment Agency [12], [13], Forum Waschen [14], Bund der Energieverbraucher e.V. [15], Umwelt Briefe [16], n-tv [17], N24 Nachrichten [18]).

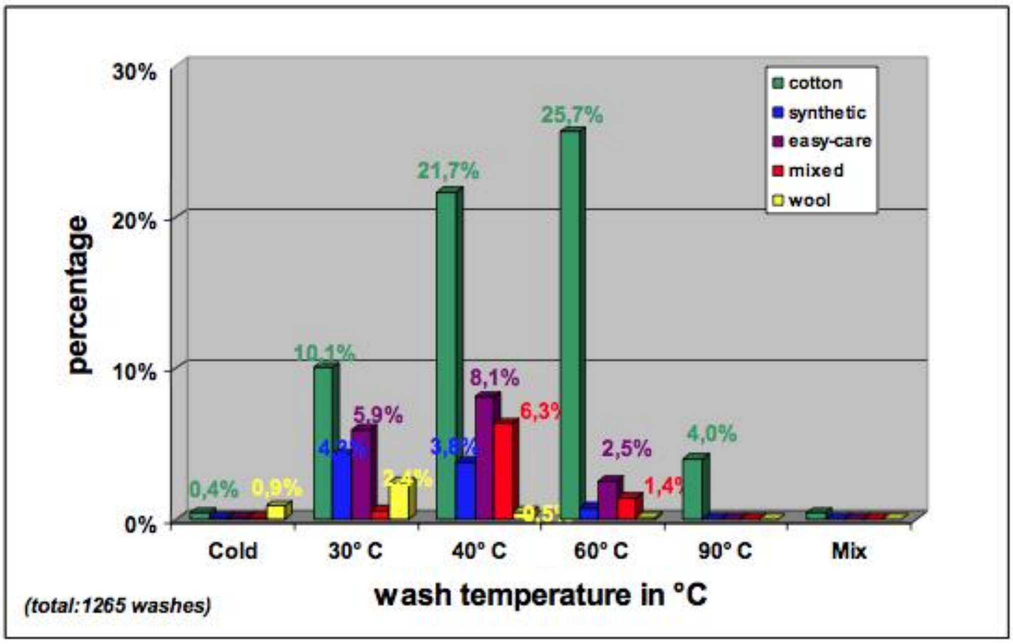
Cold Wash is Widespread in the United States, Japan, China and Spain

In the United States, Japan and China, for example, «cold wash» is common.[1] In Europe, the dissemination of «cold wash» differs. In Spain, «cold wash» is common. Also in Italy and France consumers do wash cold, but far less than consumers in Spain.[2]

In Germany, Austria, Switzerland and in Eastern Europe «cold wash» is not a common practice [19]. In Switzerland, for example, around 5% of the consumers still choose the boiling wash cycle. 80% of the laundry is washed at 60°C or 40°C. The 30°C cycle is chosen by around 15% of the consumers and only a marginal percentage of the consumers use «cold wash» (< 0.5%) [20]. Alike data were found in Germany [1], [6]. We estimate that the average washing temperature in Europe is around 40°C.

[1] The washing machines often do not have their own heating element. In the United States, washing machines usually are provided with the warm water from hot water heater storage tanks, in Japan and China cold water flows in from the main.

[2] In countries in which «cold wash» is widespread, often highly alkaline chemicals which strongly stress the environment are used to achieve a good washing result (e.g. javel water, peroxide). Additionally, the washing machines used in these countries usually consume a lot of water (e.g. in the United States: 100 – 150 litres for 5 kg laundry [21]).



Distribution of wash cycles and temperature in Germany [1]

70% Less Energy Consumption at 20°C instead of 60°C

The most energy intensive process during washing is the electric heating of the cold tap water up to 30°C, 40°C, 60°C, 90°C or even 95°C. Thus, «cold wash» uses by far the least electricity.[3]

The electricity consumption of the washing machine depends primarily on the selection of the washing temperature. Washing with a typical appliance (energy efficiency class A+) at 20°C instead of 60°C saves 70% electricity [20]. The savings potential depends also on the energy efficiency class of the washing machine (according to the EU energy label [22]) and the individual model. In best performing models the saving tends to be smaller. The temperature of the inflowing tap water also has an impact. The lower it is, the smaller the savings. Furthermore, the amount of water to be heated is decisive.

Energy Savings Potential of 15 – 25 TWh per year in Europe

The EU-27 washing machine stock in the residential sector was estimated to be around 167 million units in 2005 [2], [23]. Their energy consumption is estimated at around 51 TWh per year [1], [2], [3].

If the most commonly selected washing temperatures of today (40°C/60°C [1], [6], [20]) are shifted down, significant savings will result: If in the mid-term the 60°C cycle only is selected every tenth wash and the rest of the laundry is washed at 40°C and 20°C (approximately fifty-fifty), the electricity consumption is reduced by about 30% (conservatively calculated) [20]. Depending on the household size, this results in a saving of around 50 to 150 kWh or around 8 to 22 Euros per year.[4] In some cases, this does not sound very impressive, but in total it takes on another dimension: relative to the EU-27 savings of around 15 TWh per year (15 billions kWh) are possible in the mid-term. This equals 1,5 times the annual production of the nuclear power plant Grundremmingen bloc B (10,3 TWh per year) or almost half of the annual production of the 4 nuclear power plant-blocs in Cattenom (37 TWh per year).

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[3] Energy is also used for the motor (e.g. rotation of the washing machine drum, spin-drying of the laundry) and for standby/left-on. «Cold wash» needs (almost) no electrical heating, which raises the share of energy used by motor and standby/left-on.

[4] Assumption electricity tariff: 0.15 €/kWh, there however can be large differences depending on country or electrical utility.

In the long term, if «cold wash» is even more frequently used[5], a savings potential of 50% is possible [20]. For EU-27 this would correspond to around 25 TWh less energy consumption per year (25 billion kWh), which corresponds to the double annual production of the nuclear power plant Isar block 2 (about 12 TWh per year) or two-thirds of the annual production of the 4 nuclear power plant-blocks in Cattenom (37 TWh per year).

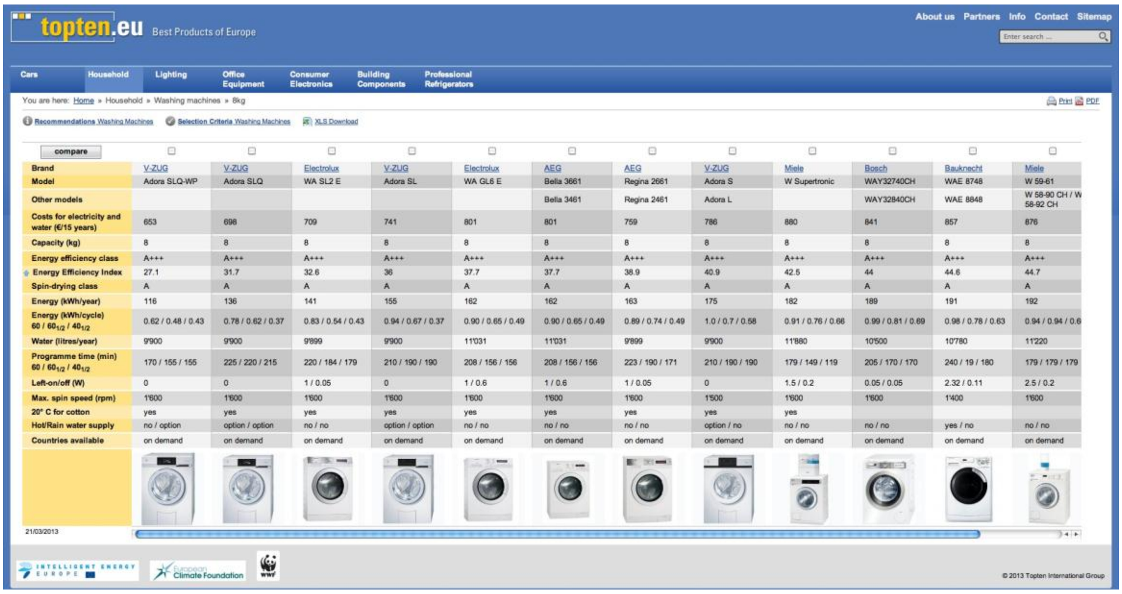
Consumers that use low washing temperatures, continually contribute to 30% – 50% less electricity consumption and CO_2 emissions caused by washing and thus contribute to the sustainable conservation of the environment.

Energy Efficient Washing Machines are the Trend in Europe

www.topten.eu – Overview on the Most Energy Efficient Washing Machines in Europe

Washing machines are continuously optimized, particularly regarding their energy and water consumption. Today's best appliances are characterized by best energy efficiency (A+++) and best spin-drying efficiency (A) according to the EU energy label for washing machines [22].[6] Additionally, their water consumption is low.[7]

An overview of the most energy efficient washing machines available on the European market, is presented by the international online search-tool Topten – www.topten.eu [25]. Topten also declares whether the washing machine offers a «cold wash» cycle.



Brand	V-ZUG	V-ZUG	Electrolux	V-ZUG	Electrolux	AEG	AEG	V-ZUG	Miele	Bosch	Bauknecht	Miele
Model	Adora SLQ-WP	Adora SLQ	WA SL2 E	Adora SL	WA GL6 E	Bella 3661	Regina 2661	Adora S	W Supertronic	WAY32740CH	WAE 8748	W 59-61
Other models						Bella 3461	Regina 2461	Adora L		WAY32840CH	WAE 8848	W 58-90 CH / W 58-92 CH
Costs for electricity and water (€/15 years)	653	698	709	741	801	801	759	786	880	841	857	876
Capacity (kg)	8	8	8	8	8	8	8	8	8	8	8	8
Energy efficiency class	A+++	A+++	A+++	A+++	A+++	A+++	A+++	A+++	A+++	A+++	A+++	A+++
Energy Efficiency Index	27.1	31.7	32.6	36	37.7	37.7	38.9	40.9	42.5	44	44.6	44.7
Spin-drying class	A	A	A	A	A	A	A	A	A	A	A	A
Energy (kWh/year)	116	136	141	155	162	162	163	175	182	189	191	192
Energy (kWh/cycle) $60 / 60_{1/2} / 40_{1/2}$	0.62 / 0.48 / 0.43	0.78 / 0.62 / 0.37	0.83 / 0.54 / 0.43	0.94 / 0.67 / 0.37	0.90 / 0.65 / 0.49	0.90 / 0.65 / 0.49	0.89 / 0.74 / 0.49	1.0 / 0.7 / 0.58	0.91 / 0.76 / 0.66	0.99 / 0.81 / 0.69	0.98 / 0.78 / 0.63	0.94 / 0.94 / 0.6
Water (litres/year)	9'900	9'900	9'899	9'900	11'031	11'031	9'899	9'900	11'880	10'500	10'780	11'220
Programme time (min) $60 / 60_{1/2} / 40_{1/2}$	170 / 155 / 155	225 / 220 / 215	220 / 184 / 179	210 / 190 / 190	208 / 156 / 156	208 / 156 / 156	223 / 190 / 171	210 / 190 / 190	179 / 149 / 119	205 / 170 / 170	240 / 19 / 180	179 / 179 / 179
Left-on/off (W)	0	0	1 / 0.05	0	1 / 0.6	1 / 0.6	1 / 0.05	0	1.5 / 0.2	0.05 / 0.05	2.32 / 0.11	2.5 / 0.2
Max. spin speed (rpm)	1'600	1'600	1'600	1'600	1'600	1'600	1'600	1'500	1'600	1'600	1'400	1'600
20° C for cotton	yes	yes	yes	yes	yes	yes	yes	yes	yes			
Hot/Rain water supply	no / option	option / option	no / no	option / option	no / no	no / no	no / no	option / no	no / no	no / no	yes / no	no / no
Countries available	on demand	on demand	on demand	on demand	on demand	on demand	on demand	on demand	on demand	on demand	on demand	on demand

Screenshot www.topten.eu: Example washing machines of 8 kg. The best appliance in this category (V-Zug, Adora SLQ-WP) due to its integrated heat pump has an Energy Efficiency Index (EEI) of around 27. This is 40% better than the EEI-limit (46) for the best class A+++. www.topten.eu lists the best performing washing machines with a capacity of less than 8 kg, 8 kg, and more than 8 kg.

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[5] 75% at 20°C, 20% at 40°C and 5% at 60°C.

[6] The washing efficiency is not declared on the EU energy label, because the class A is mandatory according to the EU-Ecodesign-regulation [24].

[7] E.g. best performing 8 kg-appliances according to www.topten.eu [25] use between 9'900 litres of water for 220 standard uses (declaration according to the EU energy label). This is on average 45 litres per cycle.

20°C Cycle is Mandatory from 2014

In older washing machines the 30°C cycle for delicates or woolly laundry-items is often the lowest washing temperature that can be selected. However, this must not be an obstacle for consumers to wash cold: in this case the laundry can be washed in the 30°C cycle for delicates[8] and can be spun again at higher spin-speeds – especially when the laundry will be dried by machine (tumble dryer, air dryer).

Already in 2011 several machines offered a 20°C cycle [26]. In the meantime, some manufacturers have even gone a step further and for their latest generation of appliances created a 15°C cycle. Thus, even less heating energy is needed. Whether 20°C or 15°C, these cycles are specifically designed for «cold wash» and include correspondingly optimized mechanics and extended washing time to achieve good washing results.

The EU has recognized the high energy saving potentials of «cold wash». Therefore, the EU-Ecodesign-regulation states that from December 2013 a 20°C cycle for washing machines is mandatory [24].

Detergents for Low Washing Temperatures are Available on the European Market

Nowadays all known European detergent manufacturers offer detergents designed for the washing temperature range of 15°/20°C to 60°C or 90°/95°C [19].[9] Such detergents exist as heavy-duty detergent (with / without bleach) and colour detergent.

There are Some Prejudices against Cold Wash

On a rational level, consumers may be aware that «cold wash» is meaningful and both washing machines that run a 15°/20°C cycle, as well as detergents for low washing temperatures are available on the European market.

However, the emotional level is often much stronger and supercedes the rational level, because washing also has a lot to do with tradition and habits [19]. The reason why washing habits cannot easily be changed from hot to cold has a lot to do with the fact that there remain some reservations about the «cold wash». The concerns are related to the detergent, such as doubts about the washing result at low washing temperatures, dosage and chemicals, and to hygiene of clothing and textiles, the formation of biofilm in the washing machine.

Prejudices against the Detergent

Detergency: does the laundry get clean at 15°/20°C?

Clothing and textiles shall be clean after washing.[10] However, many consumers fear that their laundry at 15°/20°C does not get clean. Is this true? And what type of laundry is suitable for «cold wash»?

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[8] The use of the wool cycle for non-woolly laundry-items is not recommended. The wash temperature is low but it lacks the necessary movement of the laundry to achieve a good washing result for non-woolly laundry-items.

[9] Henkel, Mibelle Group (largest Swiss detergent manufacturer), Procter & Gamble, Unilever.

[10] According to the Sinner circle – the mechanism of action, with which the cleaning processes (e.g. in the washing machine) are organized and accomplished [27] – a good washing result always depends on the interaction of the four factors mechanics (i.e. the agitation of the laundry in the drum), temperature, time, and chemistry. Mechanics, wash temperature and wash time are controlled by the washing machine and by the selected washing cycle, respectively. The chemistry is given by the chosen detergent. All four factors are interdependent, but inter-changeable in size. If one of the factors is changed, it must be

With detergents designed for 15°/20°C cycles slightly and normally soiled clothing and textiles get clean at these washing temperatures [19].[11] This is thanks to the improved and more effective formulations in recent years.[12] «Cold wash» thus is suitable to all the clothing for office life, but also underwear, bed linens, kitchen linen and towels.[13]

Regardless of the effective wash performance of a detergent, the consumers ultimately decide whether the laundry from their point of view has become clean or not. If a wash result is judged as unsatisfactory however, it is not necessarily the low washing temperature that is at fault. The washing result is also significantly influenced by the pre-sorting of the laundry, the (pre-)treatment of stains[14], the correct loading of the washing machine[15], the usage of a suitable detergent[16], the correct dosage of the detergent[17] and the correct cycle selection[18]. Thus, washing requires a broad knowledge by the consumer – regardless of the washing temperature!

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compensated with one or more other factors in order to achieve the same satisfactory washing result. If, for example, the wash temperature is lowered to 15°C/20°C, it needs either higher mechanics, so that the laundry is milled enough or an extended wash time, so that the detergent has enough time to have its full effect, or improved chemistry of the detergent.

[11] The statement that slightly and normally soiled clothing and textiles get clean at 15°C/20°C is based on the knowledge of [19]. Published tests, as mentioned in the section «Status of Literature», have only a limited relevance as they primarily focus on the removal of stubborn stains, which is not the usual case. All detergent manufacturers do test the wash performance of their detergent regularly [19]. However, these results are intended for internal purposes and therefore are not citable here. There are two methods to measure the wash performance (cleanliness): a standardized and a non-standardized method. The standardized test method measures the remissions of soiled fabric strips (for bleach, surfactants (oil), etc.) before and after washing. Observed differences base on measurements and usually are not recognizable by the naked eye. The measured values of various test institutes are difficult to compare because each institution is testing slightly different. The non-standardized method is based on so-called in-home use tests in which the washing result is visually judged by eye. The assessment is subjective, because each household has its own test stains and feelings, which means clean.

[12] The detergency at «cold wash» significantly was increased during the last few years. Progress was made especially in the area of enzymes and surfactants [19]. For the latest generation of low-temperature detergents other enzymes are used than few years ago and the proportion of enzymes that are effective particularly at low temperatures has been increased. In addition, other surfactants and combinations are used as before, which act even better in cold temperatures. Enzymes are proteins or protein body. They reduce contaminants as protein, fat, starch, etc. by splitting these specifically. They are made from genetically engineered organisms. Some manufactures declare this. Surfactants are surface-active substances (dirt solver). They take over the main task when washing. They accelerate the wetting of the fibres, replace dirt and prevent it settles back on the fabric. Surfactants are usually either produced from fossil resources (oil) or renewable resources (palm kernel oil).

[13] For heavily soiled clothing and textiles (what usually only is rarely the case) one is with a 60°C-cycle and bleach-containing detergent on the safe side. In this category are e.g. filthy rags, working clothes of workmen, clothes of children playing outside, and baby clothes.

[14] (Pre-)treatment of stains: Stains – from egg to fat splashes up to berries – have to be removed and the laundry-item has to be washed as soon as possible. The stain shall not be allowed to dry. If given, stains – especially oil and edges on shirts – have to be pre-treated with an agent (with / without bleach). If visible stains are dry and were not treated before washing, they are often immediately recognizable also after washing – regardless of the chosen wash temperature. Stains due to environmental contamination and skin fat are not seen at «first sight», but are noticed only after a certain time [19].

[15] Loading of the washing machine: At the best, the washing machine is fully filled according to manufacturer's instructions (exceptions: delicates and woolly laundry-items). Once the drum is overfilled, the laundry can not move enough. Furthermore less water is available per washing item, and so the laundry can not absorb enough water. Both lead to a reduced wash effect. In contrast, poorly filled washing machines stress the fabrics by the increased movement of the drum.

[16] Usage of a suitable detergent: When washing cold, detergent designed for low wash temperatures shall be used. Washing powder tends to wash better than liquid detergent. However, at short cycles they sometimes do not dissolve completely.

[17] Dosage of the detergent: At the best, the dosage is followed according to manufacturer's recommendations. If the dosage is too scarce, the laundry gets a greyish shimmer (greying). Generally it applies: as much as necessary, as little as possible.

[18] Cycle selection: For «cold wash» the use of the wool cycle for non-woolly laundry-items and short cycles is not recommended. The wash temperature of the wool cycle is low but it lacks the necessary movement of the laundry to achieve a good washing result. In short cycles the exposure time is shorter, so one may have to accept compromises in the washing result. On top of that, short cycles usually are no energy saving cycles.

Dosage: is more detergent needed when washing at 15°/20°C?

In general, among consumers often there is uncertainty regarding the amount of detergent they have to fill in. But must the dosage even be increased for «cold wash» so that the laundry really gets clean?

Detergents do not need to be dosed higher at 15°/20°C cycles than at other washing temperatures. It is best to adhere to the dosage recommendations of the manufacturers for slightly, normally and heavily soiled laundry.[19] The degree of soiling of the clothing and textiles is often overestimated by the consumers. Therefore, they often and independently of «cold wash» do overdose [19].

The detergent manufacturers generally are working to minimize the dose by using a synergy of enzymes and surfactants. Lower doses add up to tons, which do not need to be produced and which also do not go back into the environment [19].

Chemistry: Are stronger chemicals needed for washing at 15°/20°C?

In the context of «cold wash» and the Sinner Circle[20] also raises the question: Do detergents that are effective even at such low temperatures of 15°/20°C contain particularly strong chemicals?

For a good washing result at low washing temperatures no water-polluting javel water is necessary. In the detergents designed accordingly for 15°/20°C of all known European detergent manufacturers this task is performed by enzymes which are active and effective especially at low temperatures and little water [19]. Their use is classified as non-problematic for the environment [28].

The other ingredients in the common detergents for regular laundry (not wool or silk) are essentially the same everywhere: surfactants, builder, bleach, alkalis, processing aids, foam regulators, anti redeposition agent, dye transfer inhibitor, optical brighteners, perfumes and fragrances.

Detergents thus constitute a certain burden on our environment and waters.[21] However, the impact does not get higher with «cold wash».

Prejudices against the Hygiene

Is the laundry contaminated with germs after «cold wash» and does this harm the consumers health?

From the side of consumers in connection with «cold wash» there often exists some scepticism about hygiene.

Washing at low washing temperatures in private households with healthy individuals is considered as safe concerning hygiene [19].[22] The contact with microorganisms and bacteria is normal and is usually not dangerous for health.[23]

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[19] The dosage of detergent depends on the degree of soiling of the clothing and textiles as well as from the water hardness. Usually detergents contain around 30% substances for softening the water. In countries with very soft water (e.g. Nordic countries of Europe) sometimes builders are omitted entirely in the detergent, so that the amount of detergent required is automatically less there [19].

[20] See footnote 10.

[21] The EU Ecolabel [29] and the Nordic Swan [30] label especially environmentally friendly detergents. The «Charter for Sustainable Cleaning» [31] is the commitment of the manufacturers in the field of sustainable production and is an A.I.S.E. voluntary sustainability initiative (International Association for Soaps, Detergents and Maintenance Products, the official representative body of this industry in Europe [32]).

[22] This is different in public institutions such as hospitals and care facilities. There basically measures against a possible spread of pathogenic germs must be taken. These also cover the cleaning of textiles. But it does not make sense to transfer these measures to private households [13].

The laundry hygiene is positively supported when occasionally[24] a 60°C cycle is run with the addition of a detergent containing bleach.[25] This measure also prevents the formation of biofilm. In the situation where different households share the washing machine, such as in the laundromat or in the laundry room for joint use (as is common in Switzerland) and in case of concerns towards hygiene, it is recommended best to start the wash day with a 60°C cycle.

What about the risks of biofilm?

Consumers have also serious concerns about the formation of biofilm in the washing machine.

In the washing machine, there are always residual water deposits in which possibly not killed microorganisms find an ideal breeding environment – especially on plastic parts, hard to reach places and on the drum. This may in time lead to an unhygienic biofilm in the machine. Once inside the machine, it is very difficult to remove. So in order to prevent any bacteria and fungi from further multiplying after washing in the humid environment the laundry should always be taken out and dried as soon as possible. It is also recommended to wash occasionally at 60°C with a detergent containing bleach. Furthermore, the washing machine door and the rinse try is best left open after washing to allow the remaining moisture to evaporate.

Experience from Campaigns on Cold Washing

In 2008, the Swiss retailer Migros was one of the first sellers who was strongly dedicated to the topic of «cold wash». From June to November 2008, Migros conducted a Switzerland-wide «cold wash»-campaign for the newly developed detergents by Mibelle Group which wash also at low temperatures. Posters were hung, advertisements switched, and on TV were shown add-ons displaying the positive message about the «cold wash» detergent. The conclusions on this campaign are [33]:

- The success of such campaigns is not measurable – there are too many other influences at play such as the washing machine, prejudices, point of views and experiences of friends and neighbours, etc.
- In addition, the detergent market is heavily dependent on sales promotions and there is a constant high price war. Sometimes it is tried to cut costs by reducing quality and amount of the enzymes because these are the most expensive component in the detergent.
- For example, if consumers use less fat during frying, they get an immediate visual and sensory feedback. This is different when washing. The consumers here have no way to find out for themselves whether the washing performance is good. Instead, they have to believe that the washing machine and the detergent do their job well.
- Washing habits are usually passed from mother to daughter to granddaughter. It is important to disconnect this line. However, it takes a lot of time to get the consumers used to something new.
- Older consumers are generally very difficult to convince that something new is better. Therefore one has to start educating about the benefits of «cold wash» with the younger generation.
- The consumers need to be reminded again and again about the benefits of «cold wash», there needs to be a constant repetition and education. This is the only way the prejudices against the «cold wash» can be changed in the minds of consumers in the long-term.

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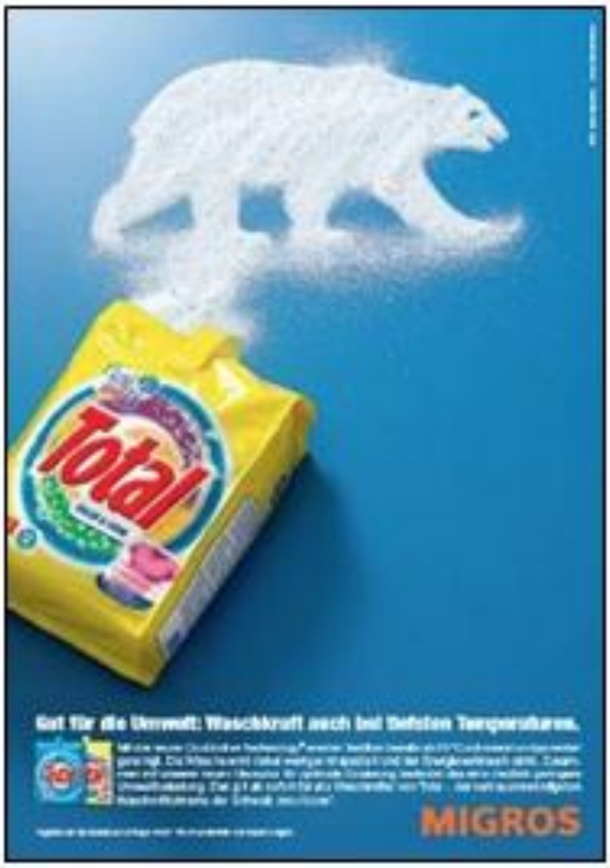
[23] To regularly wash with 60°C is recommended only for households in which people live with weakened immune system, contagious disease (e.g. diarrhoea) or a dust mite allergy. If in doubt one should consult the treating physician [13].

[24] Depending on the source «occasionally» means e.g. every 14 days, once or twice a month, every fifth laundry.

[25] If these recommendations are followed, the use of hygiene cleaners and of a hygiene cycle (75°C) is not necessary [19].



In 2008, Migros conducted a Switzerland-wide campaign on «cold wash».
Left: Migros-advertisement 2008. Good for the environment: washing power even at low temperatures. Top right: Migros-advertisement 2008: A clean victory. Total – Most trusted brand. Bottom right: Migros-poster 2008. Good for your electricity bill. Detergency even at 20 degrees.

At about the same time as the Migros also Procter & Gamble intensively promoted then their also newly developed detergent for low washing temperatures within their energy-saving initiative «cold-active». Left: «cold-active». Save energy with Ariel. Below: Shift down! Save 40% energy!

Recommendations to Promote Cold Wash

In this article it was shown that washing machines with a 15°/20°C cycle and appropriate detergents for low washing temperatures are available on the European market. The 15°/20°C cycle of modern washing machines are optimized for «cold wash» and the latest generation of detergent designed for «cold wash» is appropriate to wash slightly and normally soiled laundry at these low washing temperatures. In the case a consumer perceives the washing result as insufficient, it is not the fault of the «cold wash», but may have a number of other causes such as laundry sorting, treatment of stains, loading of the washing machine, etc. It is mainly prejudices, but also tradition and custom, that impede consumers from implementing the step towards using «cold wash» in their everyday lives.

The authors are convinced that «cold wash» is a good way to wash. The tremendous but still dormant savings potential cannot be so easily reached by any other measure of this magnitude in the whole washing process. Not seizing this opportunity, would be passing up on an opportunity where you have nothing to lose. Especially given the likely increasing electricity prices in the future, it should be an incentive for many consumers to begin using the «cold wash» in there everyday washing routine.

To promote the topic of «cold wash», the following measures are recommended:

- EU policies, washing machine manufacturers, detergent manufacturers and retailers: active and continued advertisement of «cold wash», ongoing optimization of the 15°/20°C cycles, of the detergents and of the purchasing of detergents.
- Environmental organizations, consumer organizations, energy agencies: active and continued information and education of the consumers regarding washing performance of detergents at low washing temperatures, dosage, chemicals, hygiene.
- Science, test institutes: Publication of studies (consumer and technical), continuing tests on «cold wash».

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Acknowledgements

The Topten project team gratefully acknowledges the support from

- European Climate Foundation ECF, www.europeanclimate.org
- Elektrizitätswerke des Kantons Zürich EKZ, www.ekz.ch
- WWF Switzerland, www.wwf.ch

Residential Survey to assess South Africa's Energy Saving Potential – Energy Efficiency

Theo Covary, Unlimited Energy, Yoshiaki Shibata, IEEJ

Abstract
South Africa is facing multiple challenges in its electricity sector. Key amongst these is an acute supply shortage against ever-increasing demand, local and international pressure and commitments to reduce greenhouse gas (GHG) emissions from its almost exclusive use of coal for generation and a user base which is resisting this new paradigm as it has become accustomed, until recently, to a prolonged period of surplus capacity and enjoying the lowest electricity tariffs in the world which has led to the wasteful and inefficient use of electricity.

A government to government programme between South Africa and Japan **[1]** included a study to identify and quantify opportunities to reduce electricity consumption in the middle income residential sector. The research applied the following approach: 1) collect and consolidate all available research and data; 2) supplement the available data by conducting a quantitative study; 3) consider and apply Japanese and other international experiences; and 4) use an econometric model to develop energy efficiency scenarios.

This paper provides selected findings of the main report and is broken down into four sections: 1) An introduction and high level overview of the South African electricity landscape and the study objectives; 2) Contextual background of the residential electricity sector based on existing research; 3) Findings of the quantitative study; and 4) The residential electricity demand outlook and saving potential based on econometric modeling.

Introduction

Electricity Profile of South Africa

Historically, the South African electricity supply prided itself for being stable, meeting and exceeding internationally accepted reserve margin norms and the lowest tariffs in the world. The South African electricity system was built on the country's vast coal reserves.A 2005 report estimated the reserves to be the 6th largest in the world **[3]**, these reserves were successfully exploited to build an energy intensive industrial and manufacturing economy. Coal contributed 70% to the country's primary energy supply (2009) **[4]** followed by Crude Oil and Petroleum (20%), Renewables (7%), Nuclear (2%), Gas (1%) and Hydro (<1%). Eskom, the state owned utility which generates in excess of 95% of the country's electricity **[5]**, reported that its total output for 2011 was 237,430 TWh – the breakdown is shown in Figure 1**[6]**.

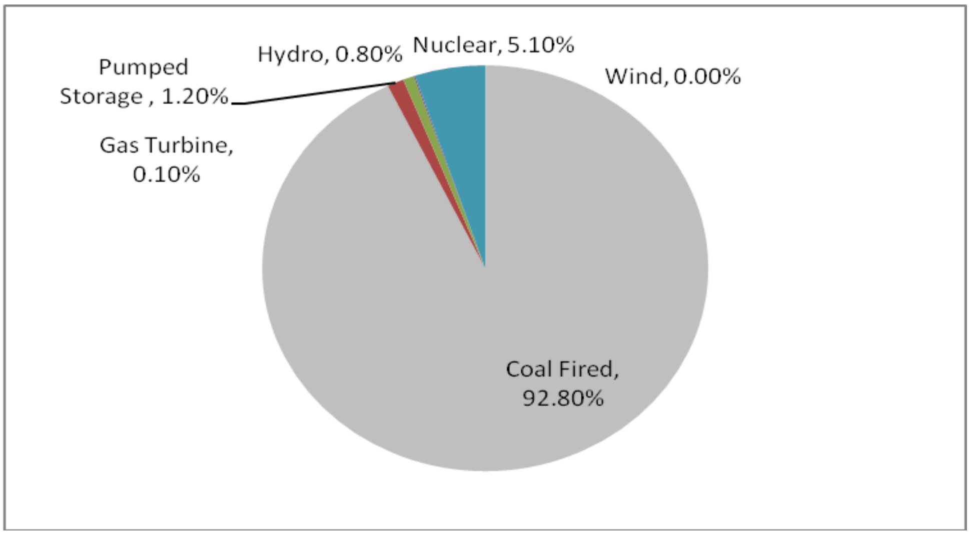

Figure 1: Electricity by energy source (2011) - Eskom

The South African Government is responding to the electricity supply challenges. The Integrated Resource Plan **[1]** (IRP, 2011) provides a planning framework for the management of electricity demand in South Africa for the period 2010-2030. The IRP estimates that electricity demand by 2030 will require an increase in additional generation capacity of over 52GW. This will be met by the construction of two new coal generation plants (which are currently being constructed), 17.8GW of renewables, 9.6GW of nuclear, 6.3GW of additional coal as well as 8.9GW of other. The IRP makes reference to Demand Side Management (DSM) rising from 252MW in 2010 to 3420 MW in 2030.The combination of the above mentioned factors means that energy efficiency (EE) is a national imperative.

The National Energy Efficiency Strategy (NEES) issued by the South African Department of Energy (DOE) in 2005 sets a national aspirational target for EE improvement of 12% by 2015 (using a 2000 baseline). The NEES covers all energy using sectors and allocates a specific target for each one. The NEES categorises the usage of energy by sector. Figure 2 lists the sectors and their final energy use. The residential sector, which accounts for 18% of final primary energy supply, was allocated a target of 10%. Key interventions identified:

- Awareness Raising
- Appliance Labelling with Minimum Performance Standards
- Efficient Lighting Programme
- Standards for energy efficient houses.

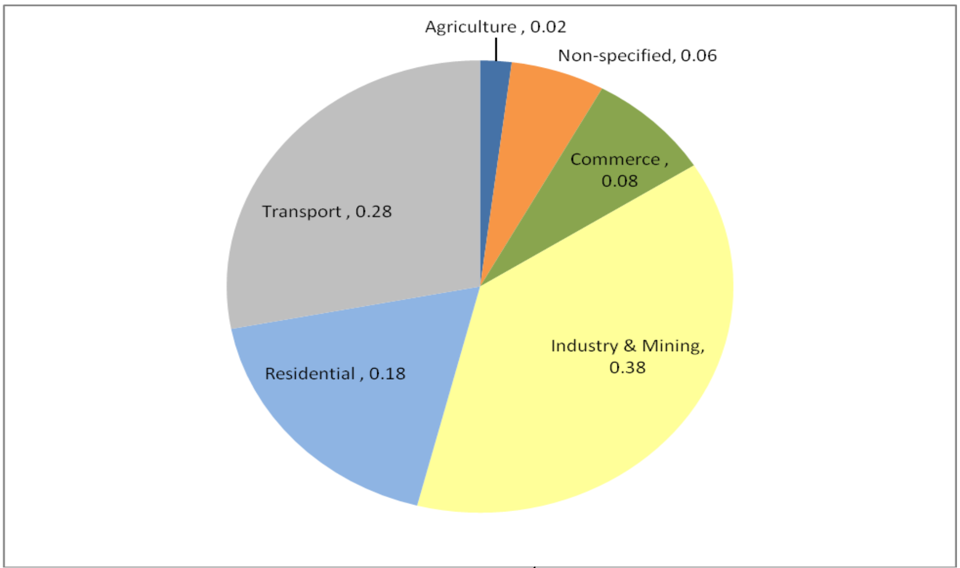

Figure 2: 2009 Final Energy use by sector[1]

The NEES, and its two subsequent revisions of 2008 and 2012, also identified barriers which are impeding the uptake of EE. A primary barrier noted is '*Lack of knowledge and understanding of EE'*. Coupled with this is the growing demand for electricity in the residential sector as:

- Low income South African households are electrified resulting in a move away from the use of coal and biomass for water heating, spatial heating and cooking;
- Middle income households become more affluent, resulting in new and additional appliances; and
- Natural population growth and urbanization.

This accelerated switch to electricity, coupled with increasing per capita consumption leads to an electricity demand growth which is greater than the total energy demand growth rate. Given the fragile state of the electricity supply and the other pressures listed above it is vital that the NEES achieves and even exceeds its targets. A key intervention is the rapid introduction of energy efficient appliances.

1 National Energy Efficiency Strategy of the Republic of South African, Department of Minerals and Energy, 2008

Rationale for the Study

The electricity landscape in South Africa has changed significantly over the last decade. Multiple above inflation tariff increases (averaging 23% per year for the period 2007 to 2012) **[7]**, rolling blackouts experienced in 2008 and a supply which is constantly under threat results in different consequences and risks for each sector. Even though the residential sector is the third largest energy user, limited research has been undertaken and most of what has been done was conducted prior to the rolling blackouts experienced in 2008. A further obstacle is that the limited research which has been conducted is generally not publicly available.

A larger study undertaken by Institute of Energy Economics, Japan (IEEJ), decided to consolidate the existing research in the residential sector via a desktop study, which was known to be limited and supplement with new research by conducting a quantitative study.

Study Objectives

The key objective was to investigate how middle-income households interact with energy and to gauge their understanding of EE, with specific reference to home appliances. The research focused on the following areas:

- Understanding EE: attitudes around the current supply shortage, billing and usage;
- Energy saving behaviour: activities in the home (behavioural changes) and investment in EE equipment;
- Appliances: understanding of EE appliances, motivation to buy EE appliances and future appliance purchases; and
- Communication and promotions: interest in EE communications, in store activity promoting EE, response to government and utility campaigns promoting EE and government EE programmes

Desktop Research - Contextual Background of the South African Residential Sector

Breakdown of Consumption

The Community Survey undertaken by Statistics SA in 2007 **[8]** reported that electricity is the primary energy source in households for lighting (80%), cooking (67%) and heating (59%). Further insight was provided by the census **[9]** which was done in 2011 which found that 84% of households were using electricity for their lighting needs. The use of other selected household appliances is shown in Figure 3 below.

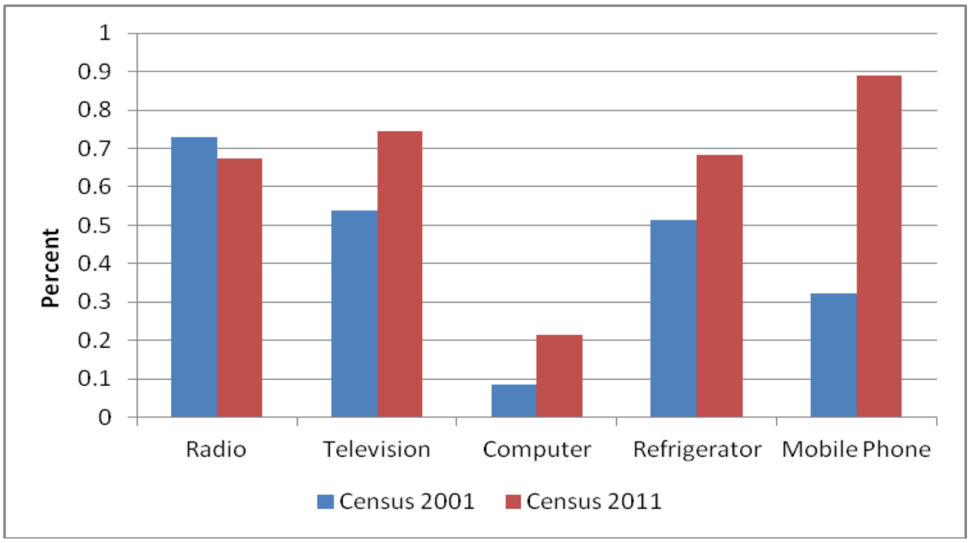

Figure 3: Percentage of Households with selected household goods in working condition: Census 2001 and Census 2011

Note: All contents of this study are the copyrights of JICA unless otherwise stated

A publication based on internal research conducted by Eskom **[10]** estimated that the average South African (middle income) household consumes 1,100kWh per month. Water heaters, domestic refrigerators, lighting and cooking appliances were the largest household electricity consumers. - The breakdown is given in Figure 4, while Table 1 provides a breakdown of the end use of all fuels for middle income households.

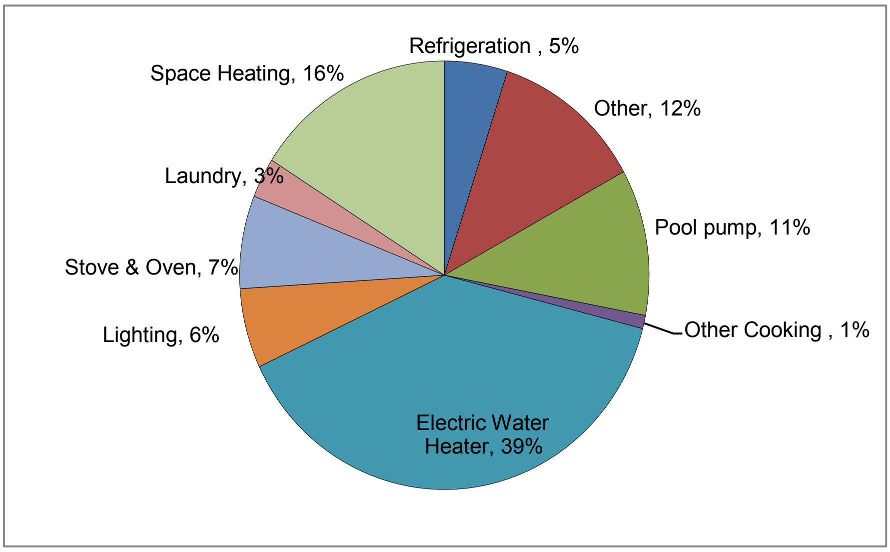

Figure 4: Average Household Electricity Usage Across the most common Appliances, Eskom

Table 1: End-Use Shares by Fuel for Middle Income Electrified and Non-Electrified Households[2]

End-Use	Electricity	Oil Paraffin	Coal	Biomass Wood	Oil LPG
Middle Income Electrified					
Lighting	9%	-	-	-	-
Cooking	12%	67%	-	86%	28%
Space Heating	10%	18%	100%	10%	72%
Water Heating	35%	15%	-	4%	-
Refrigeration	9%	-	-	-	-
Other	25%	-	-	-	-
Total	100%	100%	100%	100%	100%
Middle Income Non-Electrified					
Lighting	-	1%	-	-	-
Cooking	-	21%	49%	68%	28%
Space Heating	-	25%	51%	13%	72%
Water Heating	-	53%	-	19%	-
Refrigeration	-	-	-	-	-
Other	-	-	-	-	-
Total		100%	100%	100%	100%

Quantitative Research

Methodology and Sample

The South African Advertising Research Foundation's (SAARF) Living Standards Measure (LSM) has become the most widely used segmentation tool in South Africa, and is endorsed by the Southern

2 Energy Research Centre, University of Cape Town (UCT) , 2012

African Market Research Association (SAMRA). In the SAARF LSM, the population continuum is divided into ten groups, from 1 at the bottom end, to 10 at the top. This study targeted homes in the LSM 5-8 category. Respondents for the quantitative research were interviewed using a face-to-face approach and were selected to be representative of the South African population. The sample structure, as defined by the various demographic splits is shown in Table 2 below. As South Africa has different climatic zones, two major metropolitan areas were selected (Johannesburg and Durban) as there was a hypothesis that the climate may influence the use of energy, particularly during the winter months as Durban has a sub-tropical climate. However, the study found that electricity consumption in Durban is not significantly lower than Johannesburg's at any time during the year.

Table 2: Sample Structure

Demographic Type	Demographic	Percentage	Count (n = 415)
Race	Black	84%	348
	White	8%	35
	Indian	5%	22
	Coloured	2%	10
LSM	5-6	58%	240
	7-8	42%	175
Gender	Female	52%	217
	Male	48%	198
Age	18-34	50%	207
	35+	50%	208
Region	Johannesburg	62%	258
	Durban	38%	157

Findings of Quantitative Study

Understanding of EE

When asked to define 'EE', the concept is understood at a very generic level, with the majority citing "*using less energy or electricity*" in explanation of the term. Most respondents link EE to concerns around energy capacity, understanding that it is necessary to be EE because of the current supply shortfall being experienced in the country. Verbatim responses include:
'I am concerned about the energy shortfall, I think we need to save energy where we can', ***'it's to get us to make an effort to save power and for us not to pay so much on our bills'*** and ***'to help Eskom to save power by not using to much lights'***.

The understanding of "*using less energy to get the same results*" is articulated at very low levels - ***'it's using products that can perform the same job but use less electricity',*** indicating a need for market education around the concept of EE. Once consumers are in a position to fully understand what EE means, there is greater potential for a behavioural shift within this context.

Attitudes towards Electricity

A high awareness of the electricity crisis is evident, and with this, there is strong awareness and understanding of the need to save electricity, and the need to change personal behavior. While a concern for the country and for Eskom's predicament is evident, respondents tend to make the link between saving electricity and saving money. Throughout the study, a trend is evident whereby the more energy saving (which includes fuel switching) has a personal impact on consumers (financial), the more engaged they are with the process.

Electricity Billing

A high distrust of the billing process is evident. Consumers don't appear to fully understand how they are billed, both in terms of what is owed and how this is calculated, although the calculation elicits lower understanding as compared to what is owed. At a total level, 6% of respondents do not look at their bills at all. This trend is seen most strongly in the older sample who are the most disengaged from the concept of EE. Within this context, there is a very high incidence (61%) of people feeling that they are being over-billed. Electricity price increases are strongly noted at 76%, with the majority claiming that these increases have affected them more than anticipated. Due to the effect these increases have had, electricity monitoring has become far more stringent over the past 4 years, and consumers are generally much more careful with their electricity usage.

Electricity Saving Behaviour

- **Activities in the Home:** In keeping with an understanding that personal behaviour needs to change, everyday activities such as turning off lights and using EE light bulbs are taken up at fairly high levels – as shown in Figure 5. The less affluent and younger sample displays the highest incidence of these everyday behaviour changes. A clear lack of engagement amongst the more affluent sample was found – while these respondents do notice electricity price increases, the impact on their lives is evidently not strong enough, and thus the incentive for real behavioural changes is lower.

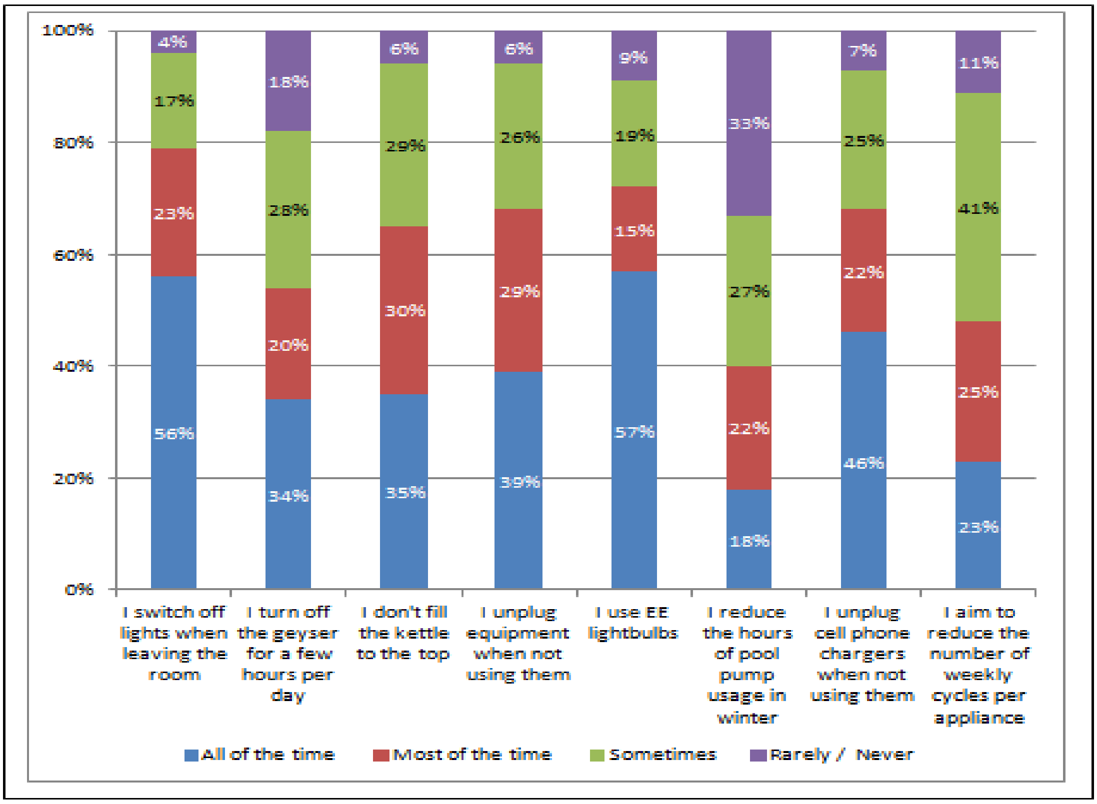

Figure 4: Energy Saving Activities

- **Home Modifications:** When asked '*What changes have you made to your home to help with energy savings?*, home modifications are not yet the norm. The respondents who appear the least engaged in everyday activities are also the respondents who display the highest incidence of having changed to prepaid electricity. This is indicative of a trend whereby consumers, who can afford to, are more inclined to make a once-off change with a higher cash outlay but lower hassle factor, as opposed to making smaller everyday changes. The mentality here is one of "I have done my bit, and I have solved my personal problem. Now I don't need to worry about the electricity crisis". A breakdown of activities is provided in Table 3.

Table 3: EE modifications made to the home (%)

Activity	Total	LSM 5-6	LSM 7-8	Young	Old
Switched to pre-paid electricity	39	36	42	36	41
Made energy source switch (i.e: electricity to gas for cooking)	22	19	29	27	20
Installed Solar Water Heater or Heat Pump	10	9	11	11	9
Installed a timer on the electric geyser	9	5	12	5	11
Installed a geyser blanket	2	1	7	2	4
Installed ceiling insulation	5	2	9	6	2

Household Appliances

- **Understanding EE Appliances:** Understanding of EE within the context of an appliance speaks to using less electricity than another appliance, or to using less electricity to get the same result. Where on a conceptual level, "EE" was understood in generic terms, the concept is better understood when applied to an appliance. Once consumers have understood and bought into the benefit of an EE appliance, this could be used in leveraging education around EE at a broader level.

- **EE Appliances in the Home:** The incidence of having EE appliances in the home is still quite low, at 27% on a total level. This is driven predominantly through energy saving light bulbs, although fridges and microwaves are the most prominent large appliances that have energy savings labels. The younger sample is driving the ownership of EE appliances, which is in keeping with their far higher engagement with the electricity crisis and the need to change personal behaviour to overcome the problem.

- **Factors influencing EE Appliance Purchases:** As would be expected, price (48%) is the key driver to appliance purchase choice. Warranty's and after sales support (47%) is also very important in the purchase making decision. EE, at 23%, comes in as the fourth most important driver, indicating that there is awareness of the long-term benefits of purchasing an EE appliance. The other 'extremely important' consideration in the purchase making decision are: Safety Features (23%); Design / Features (20%); Brand (19%); Size / Capacity (15%) and Colour (9%). As 'buy-in' to the benefit of EE appliances increases, so too should the relative importance of EE when purchasing a new appliance.

- **Appliances in the Home and Future Purchases:** Fridges, followed by CRT TV's and microwaves are the most commonly owned appliances. Ovens and electric water heaters (geysers) are owned predominantly by the more affluent sample. These two appliances are also perceived as using the highest amount of electricity. The perception that geysers use the most electricity, while accurate, is clearly driven through the communication regarding switching off geysers when not in use. Washing machines drive future purchase intent, while geysers and ovens are cited strongly as a subsequent desired purchase, after the more 'essential' washing machine and microwave.

Communication and Promotions

- **Interest in EE Communication:** Claimed interest in finding out more about EE and savings is high at 75% at a total level. Interest is significantly higher in the younger sample (84%) as compared to the older sample who only displays an interest at 64%. Mass media is cited as the most preferred channels for education and communication. It is evident that a two-tiered communication approach is required; mass media is required to inspire the nation to pull together in assisting with the energy shortage. However, a more tactical, 'on-the-ground' approach is required to underpin the mass media.

- **In-Store Activity Promoting EE:** In store activity promoting EE is not strongly noted. Promotions around EE are cited higher than salespeople promoting appliances due to their EE credentials, with only ¼ of the sample having been exposed to this. There is a higher incidence of EE activity in stores catering to the less affluent market.

Residential Electricity Demand Outlook and Saving Potential

Electricity Saving Potential

The energy saving potential for South Africa's residential sector is estimated by using the BUENAS (Bottom-up Energy Analysis System) model **[11]**. BUENAS is a bottom-up stock accounting model that predicts energy consumption that predicts energy consumption for each type of equipment in each country according to an engineering based estimate of annual unit energy consumption (UEC) **[12]**, scaled by projections of unit stocks. The ownership rate of appliances was estimated by the penetration model described in **[12]**, and was adjusted in accordance with the historical ownership rate data collected from existing statistics and the survey carried out along with the quantitative survey described above. Figure 6 shows the forecasted ownership rate. The model assumes growth rates of 4.5% for GDP and 0.5% for population. ***Note:*** The dots in Figure 6 represent historical data based on the survey or existing statistics

The model forecasts that the ownership rate of refrigerators will increase from 0.8 units per household in 2010 to 1.3 in 2035, and electric water heaters from 0.4 to 1.2. Although the ownership rate of air conditioner is expected to triple (0.04 to 0.12), its absolute level stays much lower than other appliances, due to demographic concentration predominantly in the moderate climate condition region.

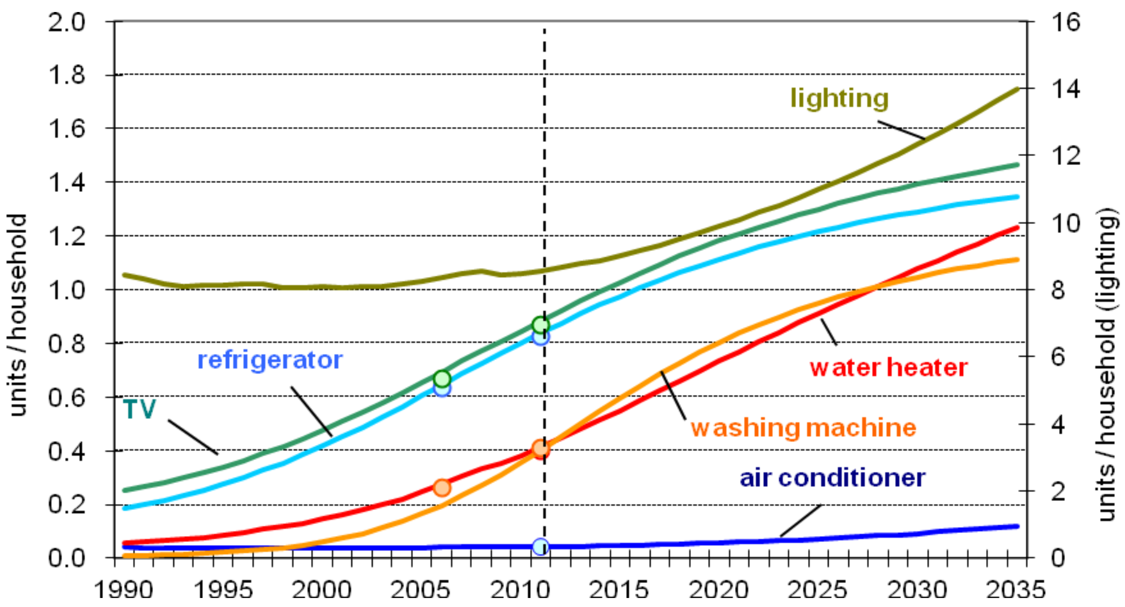

Figure 6: Ownership Rate of Household Appliances

By using a combination of the findings of the survey undertaken and existing research **[13]**, the average UEC for the selected residential appliances, based on sales in 2011, is shown in Table 4. The corresponding UEC of the best available EE technology (BAT) for the same appliances currently available in Japan is also provided. The energy saving potential is calculated on the assumption that the average UECs of sales of appliances in South Africa in 2011, which is the base year of the forecast, is at the same level as the BAT. The study assumes that the sales average UECs will reach the level of BAT in 2035 in the Energy Efficiency Case.

As there was no available data for lighting the following assumptions were made: The wattage of incandescent lamps, tube fluorescent lamps, CFLs and LED as 60W, 32W, 15W, 8W, respectively. The ownership share is assumed to change linearly from 80%, 10%, 10%, 0% in 2010 to 0%, 20%, 30%, 50% in 2050. The interpolated share in 2035 is 30%, 16%, 23%, 31%. The usage hour is set at 2.5 hours per day.

Table 4: Energy Efficiency of the Current technology and Best Available Technology

	Current (kWh/year)	BAT (kWh/year)
Refrigerators	353	132
TVs	187	112
Washing machines	181	132
Stand-by	44	26
Room air conditioners (cooling)	477	198
Room air conditioners (heating)	2,019	871
Lighting*	48	14
Water heaters	1,111	0*

Note: The UEC of BAT water heaters is zero because a solar water heater is assumed as a BAT. UEC of lighting is average weighted by ownership share of each lighting technology; incandescent lamp, tube fluorescent lamp, CFL and LED.

The estimated energy saving potential is shown in Figure 7. The potential in 2035 represents 46TWh, of which 55% comes from electric water heaters which have been replaced with solar water heater (SWH). The second largest energy saving is from lighting (19%), followed by refrigerators (12%), air conditioners (7%) and TVs at 4%. Even though the penetration rate of air conditioners is much smaller than that of the other appliances, as described above, the UEC saving potential is large as the majority of the models available on the South African market are extremely inefficient and the energy consumption is reduced significantly by BAT.

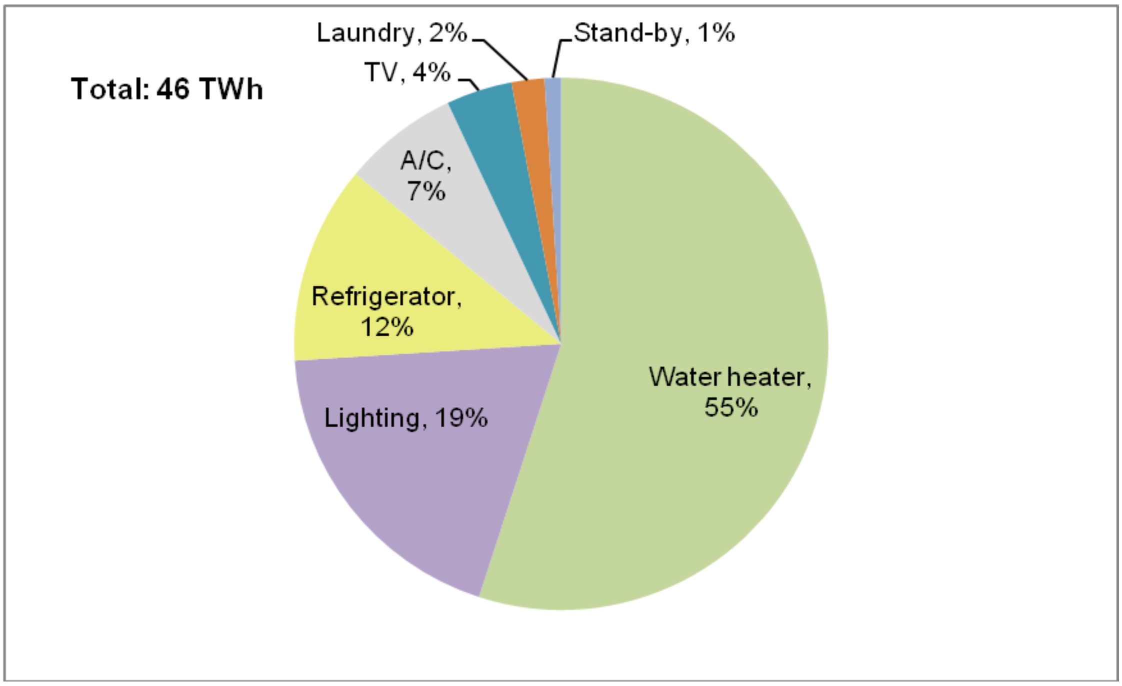

Figure 7: Residential Electricity Saving Potential in 2035

Residential Electricity Demand Outlook

South Africa's residential energy consumption, forecast by an econometric model, will grow by 3.8% annually reaching 106TWh in 2035 from 42TWh in 2010. The primary reasons for this are: 1) the Government's electrification programme; and 2) the replacement of coal with electricity for water heating and cooking by low income households. However, if appliances with BAT are introduced rapidly, through programmes such as mandatory Minimum Energy Performance Standards (MEPS) and Appliance Labelling, it is possible to curtail the electricity consumption by 31% in 2035, from the expected 106TWh to 73TWh, as shown in Figure 8. The electricity saving will be equivalent to 72% of the electricity saving potential. The solar heat consumed by solar water heater in 2035 will be 39TWh, which represents 80% of the potential solar heat. **Note:** Solar heat demand for water heating overweighs electricity consumption decrease in electric water heater, since the efficiency of solar water heater is lower than electric water heater

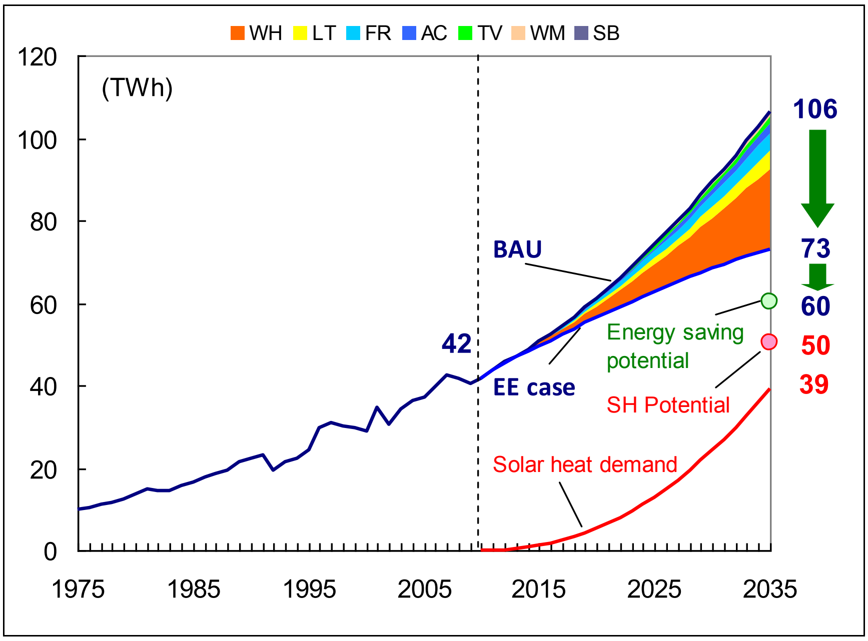

Figure 8: Residential Electricity Demand Outlook

Conclusion

The quantitative study was instrumental in that it confirmed and dispelled assumptions which are generally made about the middle income residential sector. Key findings include:

- A relatively weak understanding of what EE means and why it is important. There is a strong notion that electricity should be conserved but this is linked to Eskom's supply constraints and to a lesser extent with environmental and sustainability issues. This may result in consumers reverting to old consumption patterns and attitudes once the electricity supply constraints are addressed;

- In the post-paid market there is a poor understanding of how electricity consumption is converted to a monetary value and the way that this is presented to the consumer. Billing issues with certain municipalities has compounded the problem and there is a high distrust amongst residential consumers. This is prompting households to move to a pre-paid service. A positive outcome of the switch to a pre-paid service is that the estimated average monthly spend is significantly lower than on postpaid. While this may be perception to an extent, it is clear that pre-paid allows for closer monitoring of electricity usage, and it appears that actual Rand output on the prepaid system is lower;

- There is a strong resistance towards making behavioural changes in areas which affect lifestyle. The findings seem to indicate that consumers may be more willing to make once-off EE modifications to their homes, such as switching to pre-paid, the purchase of EE appliances, geyser blankets and CFLs; and

- 75% of consumers claim that they would like to learn more about EE and how it can benefit them. This presents an opportunity to the South African Government, Eskom and private sector companies involved in EE.

The econometric modelling found that if a business as usual path is followed and no EE measures are taken, electricity consumption in the residential sector is expected to grow 2.5 times between 2010 and 2035. Therefore, the promotion and implementation of energy-saving measures and programmes is essential to curb this rapid increase in electricity consumption - which will be driven by the switch to electricity from other energy sources as the country's electrification objectives are met and as the penetration rate of new and additional appliances / equipment continues to increase. It is thus recommended that policies are established which not only ensure that existing appliances / equipment are replaced with high-efficiency units, but that consumers who are purchasing appliances / equipment for the first time are persuaded to opt for the highest efficiency units, as the expected lifespan of these electrical appliances, once they are installed, can be as high as 10 years.

Acknowledgement

The study described in this paper is one of the key products of "The Study on Energy Efficiency in South Africa" funded by Japan International Cooperation Agency (JICA). The authors would like to thank Barry Bredenkamp from the South African National Energy Development Institute (SANEDI) and Dr Ulrich Averesch from the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for their support and contribution to this study.

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Age as a determinant of residential energy demand

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Abstract

Residential energy demand has a number of determinants. For example, the buildings' state of redevelopment, price elasticity or factors describing consumers' influence, as well as socio-economic and demographic household characteristics – including age. All else being equal, do households with older members demand more or less energy than those consisting of younger members? Answering this question is particularly relevant for long-term, capital-intensive infrastructure planning for grid-connected energy supply systems, such as gas or district heating, given that over- or underestimating future demand may involve considerable cost. With an ageing population, the EU-27 member states and especially Germany will need to plan their infrastructure accordingly. Yet, determining the effect of age is challenging because energy consumption statistics are usually not available at the level of individual households; and even if they are, it is difficult to match them with adequate socio-demographic data. First answers are found by the analysis of socio-demographic micro data. However, this type of secondary data is aggregated on the national level and needs to be substantiated on a local level because regions differ with respect to their socio-demographic and socio-economic properties.

Overcoming the difficulty of adequate data matching is at the core of an ongoing pilot project in Germany. The project will use the advanced methods of the statistical office to complement existing census data with additional data on households' energy consumption for three cities of different size. This paper reviews the literature and presents findings from the analysis of secondary data. For this purpose, micro data on energy consumption, socio-demographic household characteristics as well as building data are brought together to measure the effect of age on residential energy demand for heating and electricity. Finally, the paper describes the method used in the pilot project.

Introduction

The oil crisis in the early 1970s radically changed the way of thinking about environmental issues. During this period, research focused on how to save energy and how to make buildings, appliances and people who use them more energy efficient [1]. As a consequence of this change, researchers began to consider demographic influence on energy demand forecasts. A good example is Ehrlich's and Holdren's IPAT-model (Impact = Population * Affluence * Technology).

Today it is unchallenged that there are different factors such as technical, economic and climatic as well as consumer-related factors that influence residential energy demand. All of these factors may capture a partial truth [1]. Firstly, for a long time, technical properties were considered as the main determinants. Therefore, much effort was undertaken to explore how residential energy demand is shaped by the energy efficiency of buildings and appliances [2]. As a result, there are valid results available how building characteristics such as building type, year of construction, heat insulation or heating systems influence residential energy demand [2,3,4].

Secondly, economic influence was found in terms of price elasticity for energy, the development of supply and demand and people's willingness to invest in energy saving measures [5]. Thirdly, climatic factors have an effect on energy demand, especially for heating and cooling. In this context, the following determinants were found: average annual temperature, the days of frost during a year and temperature fluctuations. There are also factors expressing consumers' direct impact on residential energy demand as socio-demographic household characteristics and individual consumer behaviour Figure 1 provides an overview of determinants of residential energy demand.

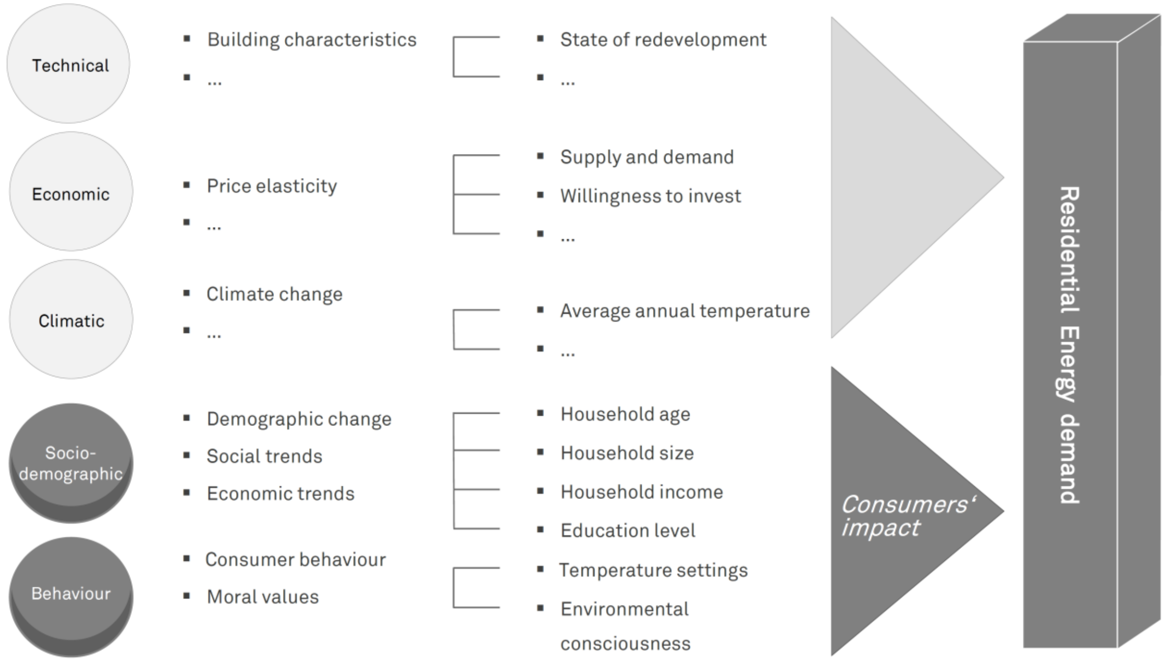

Figure 1: Factors influencing residential energy demand. ***Source: [6]***

Many studies show that there are huge differences in consumption caused by the consumer. To consider this in more detail, energy demand in households which are comparable in terms of technical, economic and climatic conditions may vary by a factor of two [7] to three or more [8,9,10]. It is unchallenged that those differences are influenced by both socio-demographic and behavioural issues related to the consumer, although they are often neglected [2,11].

For the future, Germany's energy transition ("Energiewende") will improve the thermal properties of buildings; and the overall energy use associated with building characteristics will decrease. In other words, the more effort is put into improving the energy efficiency of buildings, the more influence consumers' impact will have [12].

With regard to future residential energy demand, the effect of an ageing society on consumer structure and consumer behavior is of special interest. Therefore, this research project asks the question:

"All else being equal, do households with older members demand more or less energy than those consisting of younger members?"

Answering this question is particularly relevant for long-term, capital-intensive infrastructure planning for grid-connected energy supply systems, such as gas or district heating, given that over- or underestimating future demand may involve considerable cost. With an ageing population, Germany will need to plan its infrastructure accordingly.

The remainder of this article is organized as follows. We start by exploring the future role of consumers in Germany and describe interactions with other changing circumstances – in particular demographic change. Subsequently, we provide an overview of the relevant literature and present the data situation in Germany regarding micro-level socio-demographic analyses of energy consumption. To overcome the inherent problems of such analyses, a new method for data collection has been developed, which will be outlined at the end of the article.

How demographic ageing influences residential energy demand

Corresponding to most EU-27 member states and Western societies, Germany's population is ageing and shrinking for the long term. The latest forecast of Germany's Federal Statistical Office outlines a decline in population from 81.8 Mio. in 2010 down to 64.6 Mio. in 2060 [13]. As low fertility rates lead to smaller cohorts of young age groups, and as the baby-boom generations of the 1950s and 1960s will reach their retirement age, the proportion of young and elderly age groups will change significantly. In this context, a dominant factor is demographic ageing. The age group of "65 and above" will increase from 20% in 2010 up to 34% in 2060, and the mean age will rise by 10 years (from 41 years in 2010 up to 51 years in 2060). While the baby-boom cohorts will lead to an increasing number of age-related deaths from 2030 on, the decline in population is directly related to demographic ageing.

Another point is that demographic ageing is characterized by regional disparities. While there are spatial and regional differences regarding demographic developments there will be a coexistence of strong ageing regions an regions with a fewer demographic ageing. Figure 2 below displays the development (in %) of households "60 years and above" on the level of counties and county boroughs from 2010 until 2030. The Western States of Germany will be shaped by a fewer demographic ageing compared to the former Eastern States (except Berlin).

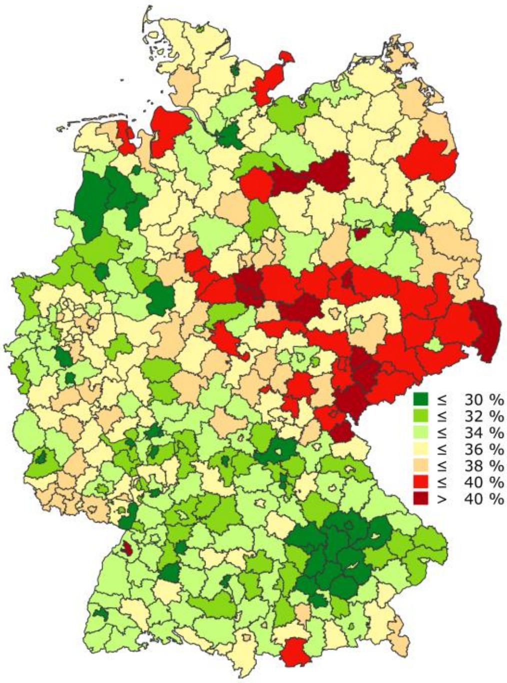

Figure 2: Increase of elderly households (60 years and above) from 2010 to 2030; Source:[13]

The three cities of different size that take part in the project described below are all located in the former Eastern States where demographic ageing will rise very fast. Germany's approach to demographic problems may be a helpful example for other EU-27 Member States where demographic change will occur at a later date. For example, In Slovakia, the age class 65 or over had a percentage of only about 12 % in 2010 (compared to 20% in Germany). Until 2060, however, its share in the total Slovakian population is projected to increase to more than 36 %. Despite those differences in the process of population aging, the overall direction of demographic development in EU Member States is unequivocal [32]

A radical decline in the German population is bound to influence Germany's residential energy demand. Since every inhabitant demands goods and services, all else being equal, a shrinking population implies shrinking (energy) demand. The focus of analysis, however, should be on private households, not on individuals. As residential energy is consumed within dwellings, households are the suitable demographic indicator [14,15,16].

In Germany the energy consumption of the household sector represents almost 30% of Germany's overall final energy consumption [17]. However, private households are a heterogeneous group and differ regarding demographic and socio-economic factors within their lifecycle. The following demographic developments may affect energy demand and energy infrastructure in different ways:

- All else being equal, a decline in population naturally means a shrinking number of consumers that may result in shrinking energy demand. It is well-known that energy infrastructure such as energy-grids or supply systems for gas and district heating are capital-intensive and lack flexibility. With an ageing and shrinking population Germany will need to plan its infrastructure accordingly. The main focus is on preventing bad investments which could mean an oversized energy infrastructure. Nonetheless, analysts agree that for the long-term overhead costs of energy infrastructure need to be financed by a shrinking number of consumers.
- The shift to an ageing society: As the consumer behavior of different age groups varies during their lifecycle, for instance regarding school books or baby food, such a lifecycle effect could also be valid for energy goods. In the context of demographic change it is relevant whether the energy consumption of elderly people differs from younger people and whether demographic ageing is a push- or a pull-factor for future energy demand [6].
- Demographic ageing strengthens the trend towards smaller households. Elderly people mostly live in single or 2-person households [18]. Ageing could have an indirect impact on households' energy demand through an associated decline in household size and consequently a loss of economies of scale in energy use at the household level. In Germany this leads to an increasing number of households in spite of a shrinking population for the medium term with an impact on the living space development: the inflexible housing stock is inhabited by smaller households. The outcome is an increase in living space per capita.
- Regional disparities will lead to different developments of demographic ageing. This requires analysis at the local level. While in shrinking and ageing regions follow-up costs of technical infrastructure will be on the rise and removal of technical infrastructure will be undertaken to save costs, growing regions need to extend their energy supply.

Literature review

So far there have been relatively few attempts to operationalize the effect of age on residential energy demand for the use in simulation models or energy forecasts. Therefore, the following paragraphs aim to review the current state of research with regard to the question whether households with older members demand more or less energy than those consisting of younger members.

Much of the research literature has shown that households' age has a significant influence on residential energy demand. Both international and German research projects provide some evidence that energy demand rises within people's lifecycles. However, qualitative and quantitative research lacks a precise deduction of age-related effects. This may be explained by the fact that several demographic and socio-economic household characteristics interact and overlap with each other. That makes it difficult to disentangle whether and to what extent higher energy consumption is directly caused by age-related consumer behaviour or indirectly by a loss of economies of scale in elderly households, housing conditions of the elderly or income related issues.

As a consequence, explanatory approaches are contradictory, and for the most part, the existence of age-related effects was underpinned by assumptions. It was at least questionable to what extent the rising energy demand is caused directly by age-related effects. By using disaggregated microdata – the Scientific-Use-Files of Germany's Income and Expenditure Survey – Timpe [6] was able to separate a clear age-related effect from overlaps with household sizes, economies of scale and housing conditions.

Age and household size

In several countries, researchers came to the conclusion that household size plays a key role for the energy use of elderly households. Against the background of demographic ageing which accelerates the trend to smaller households in Japan and many Western societies, Yamasaki and Tominaga [19] analyzed various socio-demographic factors which determine households' energy demand. They found that elderly households have a tendency to higher energy consumption per capita. A reason for this finding may be the concurrent loss of economies of scale in elderly households.

Analyses of the Residential Energy Consumption Survey in the United States also show that per capita residential energy expenditure rises with households' age [20]. Higher per capita expenditure may be explained by the fact that elderly households are rather small and therefore have less potential for economies of scale. In the case of Germany, researchers found that monthly energy expenditure increases with the age of household members, especially for heating and hot water production [14]. As 90% of the elderly households in Germany live in single-, or two-person households, a loss of economies of scale is assumed to be a reason for their higher consumption.

York found that an increase in the number of people aged 65 or over corresponds to an increase in energy consumption, all else being equal. He argues that older populations tend to a smaller household size which is seen as a push-factor for households' energy demand [21]. This may be a reason to expect that populations with a high proportion of elderly households consume more energy than those more dominated by younger households. In the future, demographic ageing will lead to smaller households and consequently to a loss of economies of scale. This may be a driver for households' energy demand.

Housing situation of the elderly

Based on consumer expenditure data, Engel found that per capita energy expenditure in Germany rises within people's lifecycles. However, Engel is rather confident that the higher energy consumption of elderly households is caused by "remanence effects" – i.e. human inertia. Those effects occur when households' living space is not adjusted to shrinking household sizes. In elderly households people tend to stay in the house which was originally built for the family, despite the loss of a partner or their children moving out once grown up. As a result, per capita living space rises with age. Therefore, the higher per capita energy demand of elderly households may be an outcome of increased per capita living space [22].

Another point is that the higher energy consumption of elderly households may be caused by their housing situation. In Japan elderly people feature a high ratio of owner-occupied and spacious housing [19]. Those houses are rather old and less energy efficient. This link is also observed in many European countries. For instance, in Germany elderly households generally live in older dwellings [23]. About 75% of Germany's real estate is older than 25 years and represents 90% of the overall energy consumption for heating [12]. Therefore, the higher energy demand of elderly households could also be explained by the fact that they live in older and less energy-efficient buildings.

Consumer behavior of elderly households

In addition, there are studies which attribute the higher energy demand of elderly households to behavioural aspects. First, Yamasaki & Tominaga assume that elderly people generally prefer higher room temperatures for space heating. They assume that in the future demographic change in Japan and many Western societies will be a push-factor for a rising residential energy demand – for the reason that the current middle-aged households with members in their 50s are the next ageing generation and "are the most active buyers of consumer durables" [19] and are therefore characterized by a more wasteful consumer behaviour in general.

Secondly, Schipper (1996) conducted a study on energy expenditure statistics in the United States. He found that energy expenditure is subject to considerable fluctuations. The increasing residential energy demand for both heating and appliances within people's lifecycles is attributed by Schipper to the consumer behaviour of elderly people. As 90% of elderly people are pensioners, they spend more time at home which, in turn, leads to more hours of heating [24]. Schipper is of the opinion that the elderly of the future "may carry with them their spending patterns of younger years, continuing to live in homes originally built to families with two children" [24].

Thirdly, Guerra Santín analyzed a combination of qualitative and quantitative data describing households' energy consumption in the Netherlands. The results showed that age is a significant factor for households' energy demand as elderly households tend to consume more energy than younger ones. Even though it was proven empirically that elderly households tend to have higher temperature settings, their higher energy consumption is primarily caused by the hours spent at home, resulting in an increase in hours of heating [4].

Moreover, research into the average annual energy requirements of households in the Netherlands, UK, Norway and Sweden by Moll [15] showed that elderly households have low energy requirements for transport and fuel on the one hand, but a high demand for gas and electricity on the other. According to Moll, this is caused by the large amount of time elderly people spend at home.

Lastly, a quantitative data-based analysis examined the energy consumption for gas and electricity of private households in Austria. In comparison to other age groups, elderly households have a higher energy demand for electricity (+42%). This may be caused by the fact that many elderly households in Austria live in single households (43%) which generally have the highest per capita energy consumption. Another point is that elderly households tend to spend more hours at home which leads to longer running hours of consumer appliances and heating systems [25].

Age & household income

Much of the previous research found an overlapping influence of households' age and income which could be another reason for the higher energy demand of elderly people. For instance, Schipper argues that both household income and living space increase within people's lifecycles. Both factors are seen as push-factors and could drive the energy consumption of elderly households. Yamasaki and Tominaga point out that a low household income acts as a negative contributor. In the case of Japan, income of elderly households is rather low compared to other age groups and is a pull-factor with respect to energy consumption [19]. However, they found that the effect of low income is rather limited.

In Germany, researchers compared households' energy expenditure in the federal states of Hamburg and Mecklenburg-Western Pomerania. An analysis of different age groups showed that monthly energy expenditure has a wide range of between 71 € and 141 € per household member for Hamburg, and between 44 € and 79 € in Mecklenburg-Western Pomerania [26]. The higher expenditure is found to be due to higher household incomes in Hamburg. Nevertheless, the comparison showed an apparent age-related consumer effect. In both states per capita energy expenditure rises with age. A limitation might be that households' living situation was not considered. Therefore, overlaps with household size and living space per capita cannot be excluded. In addition, regional price differences were not considered although their difference is small. Finally, Kriström reviewed the current literature on socio-economic influence on household energy demand, but found it difficult to correlate household age positively or negatively to energy demand, particularly due to the "delicate issue of separating age from income" [5].

Evidence of age-related effects

In many studies, age-related effects were based on assumptions. By using disaggregated microdata, the Scientific-Use-Files of Germany's Income and Expenditure Survey, Timpe [6] was able to separate a clear age-related effect from overlaps with household size, economies of scale and housing conditions. Clustering and contingency analyses with raw data also showed that monthly energy expenditure per capita increased with households' age, starting from the age groups of 40-45 years (figure 3).

The data sources for this analysis are Scientific-Use-Files of Germany's Income and Expenditure Survey (2008). The survey contains socio-demographic information regarding different life conditions of Germany's households. Those micro data were used to calculate energy consumption patterns of different household types. With a sample size of over 100.000 people in about 54.000 private households it is one of the biggest data sets of its kind within the European Union. It provides information about the income situation, domestic appliances, socio-demographic household structures and housing conditions as well as monthly energy expenditures.

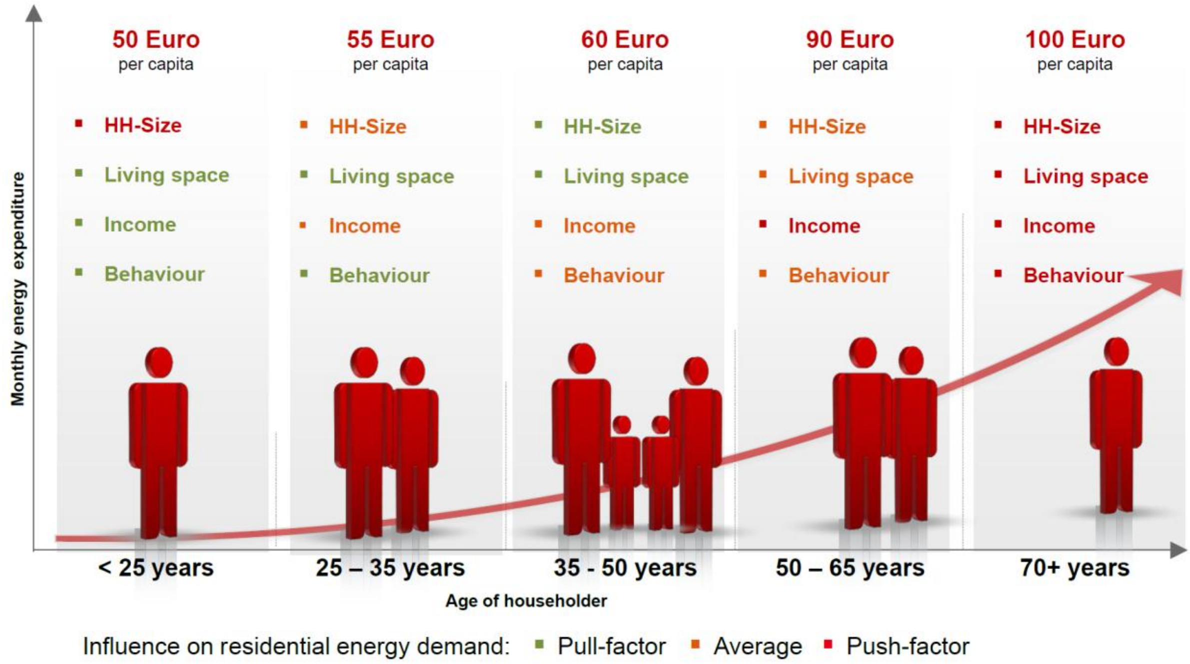

Figure 3. Monthly energy expenditure, N=54.018. Source: [6]

Nevertheless, it is not clear whether the higher consumption is caused by economies of scale, the increasing living space per capita or simply by age-related consumer behaviour [6]. Therefore, the next steps of analysis entailed reducing the interactions with overlapping factors.

An outcome of aggregating data was the consideration of identical household sizes (reducing overlaps with economies of scale) and of dwellings with similar living space (reducing overlaps with housing situation). Given the sample size, it was not possible to consider all existing household sizes. For instance, the number of elderly households with 5 or more household members is rare. Moreover, it is known that the number of households with members of under 25 years in dwellings with more than 125 m² is also small [6]. Consequently, the analysis was restricted to single- and 2-person households in specific dwelling sizes (see table 1 and 2 below).

Table 1: Energy expenditure in comparable single-households

Age groups*	**1-pers. < 50 m²**			**1-pers. 50 to 75 m²**			**1-pers. 75 to 100 m²**	
	Expenditure per capita	No. of observations		Expenditure per capita	No. of observations		Expenditure per capita	No. of observations
< 30	44.6 €	875		65.8 €	602		74.5 €	149
30-40	60.3 €	593		71.9 €	978		83.8 €	295
40-50	63.9 €	681		78.2 €	1,333		99.3 €	501
50-60	68.3 €	601		88.4 €	1,378		105.5 €	540
60-70	70.3 €	488		86.0 €	1,202		118.8 €	571
70+	73.0 €	399		92.5 €	1,123		123.9 €	586
Overall	*Ø = 63.4 €*	3,637		*Ø = 80.5 €*	6,616		*Ø = 101.9 €*	2,642

Source: [6]; Note: * age group of household head

Table 2: Energy expenditures in comparable 2-person-households

Age groups*	**2-pers. 50 to 75 m²**			**2-pers. 75 to 100 m²**			**2-pers. 100 to 125 m²**	
	Expenditure per capita	No. of observations		Expenditure per capita	No. of observations		Expenditure per capita	No. of observations

< 30	43.2 €	745		49.3 €	313		73.5 €	117
30-40	49.3 €	648		54.7 €	630		68.7 €	341
40-50	52.3 €	911		65.2 €	893		82.4 €	694
50-60	57.8 €	968		73.9 €	1,161		98.8 €	1,269
60-70	56.1 €	964		71.1 €	1,201		95.8 €	1,483
70+	55.2 €	1,109		79.2 €	1,107		98.3 €	1,114
Overall	Ø = 52.3 €	5,345		Ø = 65.5 €	5,305		Ø = 86.3 €	5,018

Source: [6]; Note: * age group of household head

Table 1 and 2 illustrate the existence of consumption differences that are likely to be caused by age-related effects. In all cases the energy expenditure increases with the age group of household head [6]. As the number of household members and the size categories of dwellings are equal, energy expenditure reaches its highest amount within the age group 70 and over (with the exception being 2-person households with dwellings from 50 to 75m²). Energy expenditure in single-households under 50 m² is almost 1.6 times higher compared to the age group of 30 and below. Similar results were found for the categories single-households 75 to 100 m² and 2-person-households 75 to 100 m². Although the increase within other categories is smaller, an age-related increase is noticeable.

To sum up, both quantitative and qualitative analyses indicate that households' age has a significant influence on residential energy demand. The increasing energy demand within people's lifecycles is mainly caused by the fact that older households feature characteristics which are push-factors with respect to residential energy demand, whereas younger households feature characteristics which are pull-factors (as illustrated in figure 3). Older households tend to be small in size (little potential for economies of scale), occupy huge dwellings (remanence effects) and have a relatively high household income. However, research by Timpe [6] substantiates that apart from this, age-related effects are visible. Those are reflected by a consumer behaviour that is seen as a push-factor with rising households' age.

Against this background of existing research on residential energy demand and its determinants, a new methodological approach has been developed to shed more light on the effect of age on household energy demand. After presenting the currently available data and its problems, the new approach is described in detail.

Currently available data

Any analysis of the influence of socio-demographic factors on energy use is limited by data availability. In Germany, at the municipal level, data is available on energy consumption, the housing situation and inhabitants' demographics.

Data on *energy consumption* is available through housing companies and municipal public utilities. Housing companies – with mainly multi-family houses in their portfolios which represent shared connections to the public energy grid – collect data for providing their tenants with regular heating and operating cost statements. Similarly, municipal public utilities have data on the energy consumption through individual connections to the electricity, gas and district heating networks. For gas and district heating, those connections are located in singly family or two-family houses.

Housing data is available through the owners of buildings and apartments. For the analysis of energy consumption, relevant housing data refers to building type, the state of redevelopment (e.g. not refurbished, partially refurbished, completely refurbished), energy source, heating system, year of construction and living space.

Socio-demographic data is with German registration offices. Their registers include a given resident's name, his address and further data such as gender, date of birth, family status, nationality and move-in date. Additional data refers to a resident's spouse, registered partner or children. The registers, however, cannot provide complete data on households that live together in the same apartment. This aggravates the retracement of data to individual households with the result that only data with average values is available for multi-family households regarding the socio-demographic data of their inhabitants. To overcome this fundamental problem, we have developed the method described in the following section.

Table 3 below summarizes the relevant data and corresponding sources.

Table 3: Available data on energy consumption, housing and socio-demographics by data source in Germany

Data	Details	Data source
Consumption	Customers' consumption of district heating, gas, electricity	Housing companies (for shared grid connections)
		Municipal public utilities (for individual grid connections)
Housing	Building type, state of redevelopment, energy source, heating system, year of construction and living space	Building or apartment owners
Socio-demographics	Given resident's name, address and further data such as gender, date of birth, family status, nationality and move-in date. Additionally: spouse, registered partner or children.	German registration offices

Method

The following methodological approach has been developed by Prognos and AGFW (the German District Heating Association) in the project "Urban restructuring and energy efficiency" commissioned by the Saxon State Ministry of Interior Affairs.

Data sources

As data sources, we rely on housing companies and associations in three different Saxon cities and municipal public utilities as described in the preceding section. In addition, the Saxon State Office of Statistics plays a central role in our approach because it has collected data on housing and socio-demographic characteristics from the registration authorities during the German Census 2011 [27,28,29]. More specifically, housing data from all 17.5 million owners of residential property in Germany has been gathered in the context of the Census of Buildings and Housing.

For *buildings*, this data includes municipality, postcode and official municipality key; kind of building; ownership situation; building type; construction year; type of heating system; number of apartments. For *apartments*, the data includes type of use; ownership situation; apartment of individuals not subject to reporting, if known; living space; WC; bath tub or shower; number of rooms [29].

For the project described here, information on the date of birth is particularly relevant for determining the age of household members.

Approach

At the beginning of the data collection process, the participating organizations coordinate with each other (separately for each participating city) to define and clarify the available data on residential energy consumption and housing. This involves characterizing the available housing data at an aggregated level. The main goal is to understand the distribution of the building stock across municipal districts and by building type (detached and semi-detached houses and multi-family houses), year of construction and state of renovation. Subsequently, the population of relevant buildings is defined dependent on data availability. The goal is to include all relevant subgroups and to increase the likelihood of having socio-demographic variance in the sample to be analyzed.

The remainder of this approach to data collection, which has been approved by the data protection supervisor of the state of Saxony in terms of privacy protection, is shown in figure 4 and described below. The approach has been derived on the premise that the data collected should be of the highest quality possible and that – at the same time – the procedure should still be practicably feasible for the cooperating partners in terms of effort required.

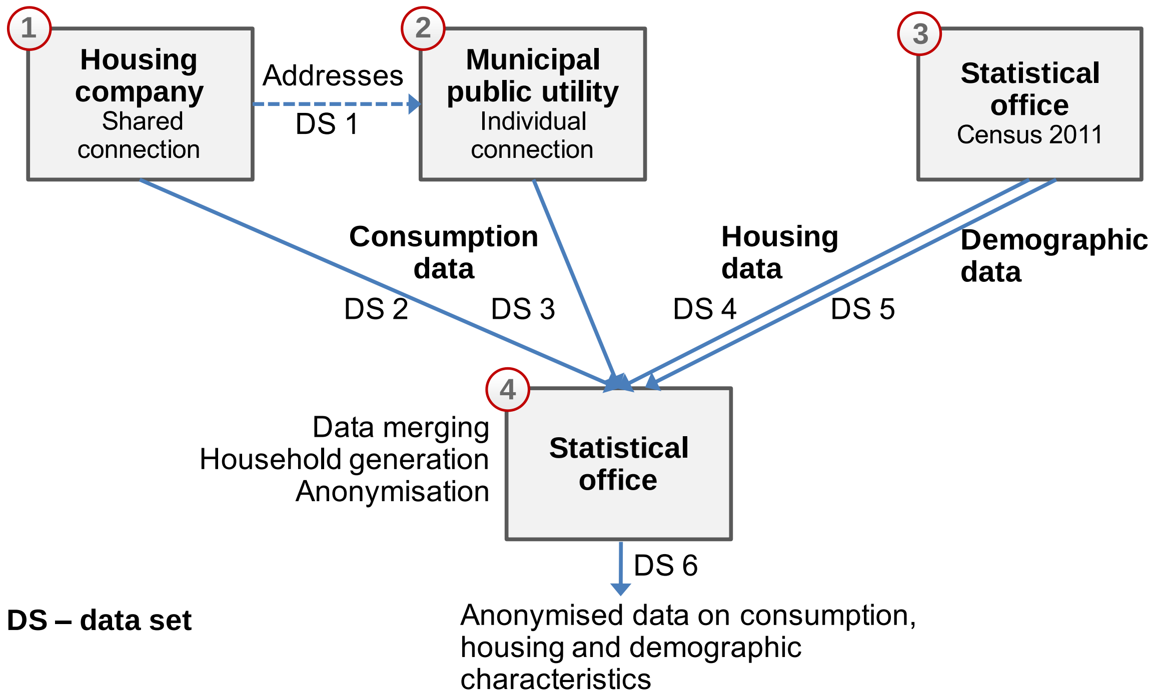

Figure 4: Data collection process

(1/2) Consumption data

The housing companies build address lists with relevant buildings and send them to the municipal public utilities (DS 1). Subsequently, consumption data from housing companies (DS 2, for shared connections) and municipal public utilities (DS 3, for individual connections) is send to the statistical office through the well-established IDEV procedure for secure online communication used by German statistical offices. Consumption data represents measured consumption, based on recent measurements. In Germany, meters are usually checked on a yearly basis. For shared connections (also see the section on available data above), consumption is attributed to individual households in conformity with the German Heating Cost Ordinance. Accordingly, property owners are generally obliged to install meters for heat and warm water consumption. At least 50 % and at most 70 % of total heating and warm water costs have to be attributed to individual households based on measured consumption. The remaining costs are attributed based on a household's share in total living space or floor space [30] .

(3) Housing and demographic data

This data is already available from the German Census 2011 (see previous section).

(4) Data merging and household generation

The statistical office applies the procedure for household generation, based on the European Union's household-dwelling concept:

"The household-dwelling concept considers all persons living in a housing unit to be members of the same household, such that there is one household per occupied housing unit. In the household dwelling concept, then, the number of occupied housing units and the number of households occupying them is equal, and the locations of the housing units and house-holds are identical." [31].

Since German registration data do not directly allow for building households, Germany's Federal Statistical Office and the statistical offices of the states have developed a new approach. By bringing together building, housing and registration data, the statistical office is able to generate households. This approach encompasses four steps [27]:

- **Building core households**: In addition to a given individual's name, registration data also encompasses the name of the individual's spouse or life partner, children or legal representative. Such supplemental data are referred to as "pointers" [own translation]. They are used to link different persons to a common "core household". Core household members need to be first-degree relatives or linked through a direct legal marriage or a registered civil partnership.
- **Identifying dwelling inhabitants:** Data from the Census of Buildings and Housing are merged with registration data. This second step is necessary because registration data does not show in which exact dwelling a person lives at a given address.
- **Using further criteria for building households:** Given that real life has more to offer than traditional father-mother-child families, further registration data needs to be considered as hints for individuals that live together (e.g. names, date of the last change in family status, etc.). At the end of this step, the majority of individuals have been matched with a specific dwelling and a household.
- **Building households by means of statistical criteria:** The remaining individuals are assigned to households on the basis of statistical averages, for example, living space per capita. As a result, all individuals who live at a given address are matched with a household and a dwelling.

Final data provision

After the anonymization of data, the statistical office provides Prognos with the data (in conformity with the requirements of §16 German Federal Statistics Law) for further analysis. The resulting data set comprises both socio-demographic characteristics such as age and household size as well as households' consumption of grid-bound energy sources, and further housing data such as living space, building type and year of construction.

Acknowledgements

This article is a revised version of the paper presented at the 2013 ECEEE summer study [33]. We thank our reviewers for helpful comments and our partners from the Saxon State Office of Statistics and the German District Heating Association (AGFW) for their cooperation. Moreover, Philip Timpe is grateful for the support he received during the completion of his Diploma thesis by Prognos and Jochen Hoffmeister in particular. Funding for this research is provided by the Saxon State Ministry of Interior Affairs. Any errors or inaccuracies remain the sole responsibility of the authors.

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Study of the Energy Related Properties' Impacts on the Price of Appliances on the Chinese Market

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Top10 China and CLASP China

Abstract

Topics: Lifestyles and Consume Behaviour

Key words: Price, Technologies, Energy Efficiency Tier, Energy Efficiency Indicator, Appliances

The price of the household appliances is affected by many factors, such as brand, design, dimension, quality, technology, and capacity, etc. The Chinese government implemented several rebate programs to promote the high energy efficient products, which is based on the assumption that high efficient products have higher price. The subsidy criteria are based on the technologies, capacities, energy efficiency tier and energy efficiency indicators, which are called energy related properties in this paper.

Six products are selected for the analysis, which are: air conditioner, refrigerator, panel TV, washing machine, rice cooker and monitor. All products are from the project named "Market Analysis for China Energy Efficient Products" (MACEEP) jointly conducted by Top10 China and Collaborative Labeling and Appliance and Standards Program (CLASP).

The analysis shows that the price of the appliances has very close correlation with the energy related properties mentioned above. It is strongly affected by the technologies, capacities and energy efficiency tiers. The technologies bring oblivious price differences for the air conditioners and washing machines. The price goes higher when the capacity increases. The price of better energy efficiency tier products is also higher than the lower tier products. However, the energy efficiency indicator has very weak correlation with the price of the products under the same technology, capacity and efficiency tier.

Introduction

Appliances are widely deployed in Chinese households. The ownership rate of major appliances (refrigerators, air conditioners, washing machines and TVs) in urban households is higher than 90%[1]. The huge number of appliances consumes significant electricity. In 2012, the appliances consumed more than 10.1 TWh of electricity, which accounted for more than 12% of all electricity in China [2]. The electricity consumption of the household appliances is expected to keep increasing in next years due to the social and economic development, urbanization and life style evolution [3]. The Chinese government has realized the importance of appliance energy efficiency to the national policy and goal of "Energy Saving and Emission Reduction", which is to achieve 16% reduction of energy per capita in 2015 compared to 2010 [4]. Both mandatory and voluntary policies and programs are implemented to improve the efficiency of the appliances. The mandatory policies include the minimum energy efficiency performance standards (MEPS) and energy label program. The voluntary programs include the energy conservation certification program, government procurement for energy conservation products and rebate programs. Three nationwide rebate programs have been implemented in recent years, which are the "Subsidy program for home appliance replacement [5]", the "Appliances to Rural Areas [6]" and the "Project to promote energy-efficient products for the benefit of the people [7]". The last rebate program subsidizes the products only based on the energy performance. More than 3 billion Euros will be awarded to high efficiency products in the program of "Project to promote energy-efficient products for the benefit of the people" from June 2012 to May 2013. The major household appliances are included, which are: air conditioners, refrigerators, washing machines, flat-panel TVs and water heaters, etc.

It is thought that the high price of efficient products is the hurdle for the market penetration [8]. The Chinese consumers also realized the importance of the energy saving and environmental protection in their purchasing process, as more than 90% of the consumers took the energy consumption into purchasing decision making [8]. The rebate programs are considered as one of the most effective policy measures to promote the high energy efficient products [9]. The subsidy criteria are based on the technology, capacity, energy efficiency tier and energy efficiency indicator, which are considered as the energy related properties in this paper.

The price is the first factor to affect the purchasing decision of the appliance [8]. It is affected by many factors, such as brand, design, dimension, quality, technology, and capacity, etc. This paper will analyze the impacts of the energy related properties compared to the price. The "technology" refers to the methods to achieve the same or similar functions by different or similar theory, which will lead to different energy consumption. The "capacity" is the parameter characterizing the size of the product/service, such as the cooling capacity for the air conditioners, volume for the refrigerators, screen sizes for the flat-panel TVs, etc. The "energy efficiency tier" is the indicator to distinguish the general energy efficiency performance in the energy label system. In China energy label system, there are two scales with either 3 or 5 tiers. In both scales the lower the tier, the higher the energy efficiency. The "energy efficiency indicator" is the efficiency performance indicator of the product set in the MEPS and disclose on the energy label.

The data of this paper is based on the project named "Market Analysis for China Energy Efficient Products" (MACEEP) jointly conducted by Top10 China and Collaborative Labeling and Appliance and Standards Program (CLASP). This project focuses on available product models on the retail market. Several data sources including retailers, independent market research companies and labeling program were integrated into one database for the analysis. The energy related data such as the energy consumption, capacity, energy efficiency tier and indicator, comes from the manufacturers' declaration for the products such as the nameplates, product instructions and energy labels. The price information was sampled from two large retail-chains (Gome, Suning [10]), on-line stores and independent information providers (ZOL, ETao [11]) in June 2012.

Impacts of the technology on the price

In the eight products analyzed in the MACEEP project, five products have at least two technologies. Separate energy efficiency requirements are set according to the technologies for air conditioners, flat-panel TVs and washing machines, while the rest of products regulate different technologies with the same indicators and requirements.

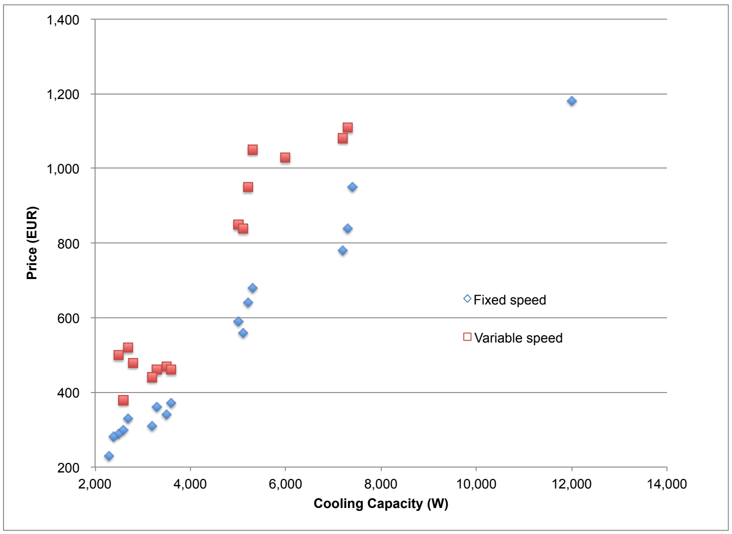

Figure 1 Cooling capacity, technology versus price of air conditioners
*n=2629

Under the same cooling capacity in figure 1, the price of the variable speed air conditioners is much higher than the fixed speed air conditioners, which is about 40% higher on average. The fixed speed air conditioner is traditional technology which appeared on the market at the very beginning of the 1980s. The variable speed technology was introduced into Chinese market in the middle of the 1990s. More than 50% consumers take the air conditioner as the most important appliance in energy saving [8]. Around 70% of consumers thought energy saving is the most important advantage of the variable speed technology compared to fixed speed technology [12]. As the air conditioner consumes significant shares of the electricity in the households, the variable speed technology targets the efficiency improvement. Variable speed air conditioners are considered as high-end products, which have a higher price than the normal products. The consumers are willing to pay a higher price for the high-end products[13].
Although the price is much higher, the market share of variable speed air conditioners increased from 8.4% in 2007 to 43.8 in 2012 [20]. The manufacturing cost of the variable speed air conditioner is higher than the fixed speed air conditioners, because it put extra controlling equipment on. However, it's doubted that the manufacturing cost difference between fixed and variable technologies is as high as up to more than 40%. A further study to disclose the manufacturing cost between those two technologies needs to be conducted.

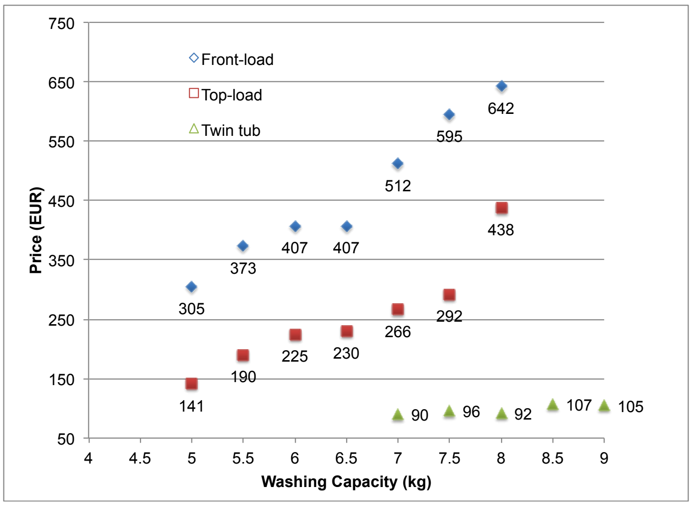

Figure 2 Washing capacity, technology versus price of washing machines
*n=1316

Comparing with the front-load and top-load washing machines in figure 2, which are generally automatically programed machines, the twin tub washing machines are semi-automatic technologies. It's the technology that needs to be eliminated from the market. The price of the twin tub washing machines is much lower than the other two technologies.

Under the same washing capacity, the price of the front-load washing machine is much higher than the top-load washing machine, which is about 80% higher on average. The top-load washing machine is traditional technology and has existed for a very long time. The front-load washing machine was introduced into China in middle 1990s. According to the testing method and energy efficiency standard - GB 12021.4-2004 [14], front-load washing machines only have better performance in the water efficiency, but it can't lead to the 80% price differences. The manufacturers and retailers usually don't take the energy saving as the selling points for the front-load washing machines. The washing quality is usually taken as the selling point [13]. The front-load washing machine is also considered as the high-end product.

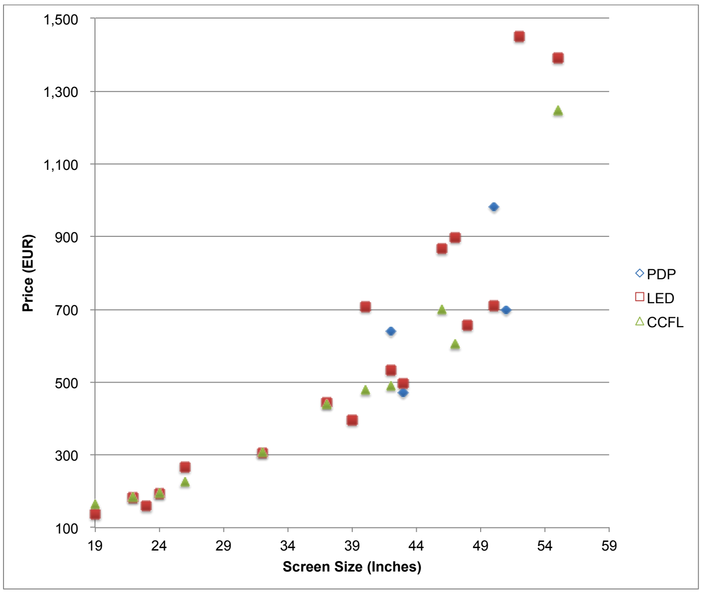

Figure 3 Screen size, technology versus price of flat-panel TVs
*n=2307
**PDP - Plasma Display Flat-panel TV, LCD - Liquid Crystal Display, CCFL - Cold Cathode Fluorescent Lamp, LED - Light Emitting Diode

The PDP and LCD technologies have principle differences in the image display. The absolute energy consumption of PDP TVs for similar size models is much higher than the LCD TVs. However, those two technologies are set different efficiency requirements in the energy efficiency standard - GB 24850-2010 [15]. The energy efficiency index (EEI) for PDP TV is improved by a correction factor and the requirement for PDP tier 1 (1.2) is 0.2 less than tier 1 requirement of the LCD TVs (1.4). The energy efficiency standard helps the PDP panel TVs to get a better energy efficiency tier. The energy label of the flat-panel TV only discloses the efficiency tiers and EEI of the TVs. The consumers can't get the power information from the TV energy label. Although the LCD TVs have much better energy efficiency performance, the price differences between the technologies is not clear. It's advertised by the manufacturers and retailers that the PDP TVs have better image quality and dynamic range.

LCD TVs dominate the market now [16] and the price of the LCD TVs has continued to decreased in recent years [16]. Under the LCD technology, there are two backlight technologies - CCFL and LED. They are regulated by the same energy efficiency requirements. CCFL launched the market for the LCD TVs with LED following and then takeing the bigger market share [16]. However, the price differences between CCFL and LED TVs is quite small and can be considered as the same price bracket. About 75% of consumers thought the LED technology had better energy efficiency [17], which is ranked at the second of all advantages of the LED technology. The first ranked advantage of LED TVs is that they have thinner shape.
The market development and competence has huge effects on the price of the LCD TVs. In 2007, the average price of a 42 inch LCD TV was more than 1300 Euros [18], the price was reduced to around 500 Euros in 2012 when LCD TVs dominated the market.

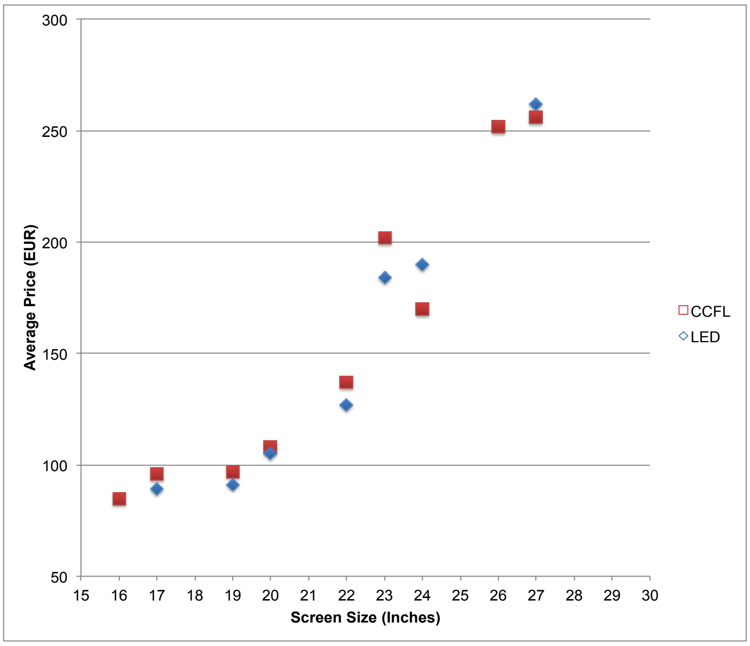

Figure 4 Screen size, technology versus price of LCD monitors
*n=652

For the LCD monitors, the price difference between the two technologies is also very small.

For the LCD displays (flat-panel TV and monitor) the price of the LED displays was indeed higher than the CCFL displays [17], when LED displays were just put into the market. Due to the rapid market development, the market share of the LED technology caught up with the CCFL, which lead to the decrease in price.

The technology has obvious impacts on the price, which is not a surprise. The new technologies bring not only energy efficiency improvement but also other advantages compared to the old technologies. For air conditioners and washing machines, the new technology has a much higher price than the old ones and the new technologies are still struggling to take more market shares. For LCD displays, the new LED technology has already taken significant market shares, which lead to the decrease of the price. The products have a differing level of importance in terms of energy saving ability for the consumers. Some products are considered more important in energy saving than the others, such as the air conditioner, which is recognized by 53% of consumers as the most important product [8]. It might be the reason that the price of variable speed air conditioners is much higher than the fixed speed ones, because the variable speed air conditioner is targeting for improving the energy efficiency of the air conditioners.

Impacts of the capacity on the retail price

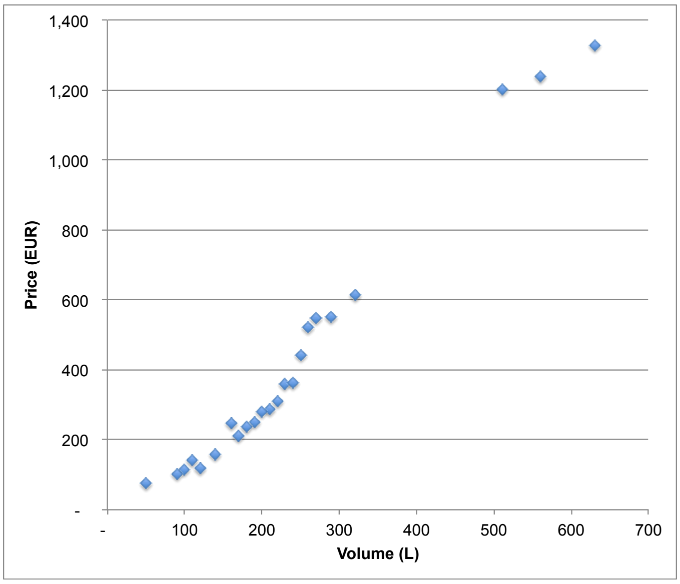

Figure 5 Volume versus price of refrigerators
*n=1667

Figure 1 to 5 show clearly that the price has very close correlation with the capacities (cooling capacity, size and volume, etc), in which the price maintains a linear increase with the capacity. The regression analysis results in table 1 also show that the price has close correlation with the capacity under the same technology.

Table 1 Regression analysis of capacity and price

Product	Technology	R2
Air Conditioner	Fixed	0.472
	Variable	0.635
Washing Machine	Front-load	0.365
	Top-load	0.353
	Twin tub	0.608
Flat-Panel TV	PDP	0.493
	LED	0.361
	CCFL	0.414
Monitor	LED	0.509
	CCFL	0.280
Refrigerator		0.571
Rice Cooker		0.004

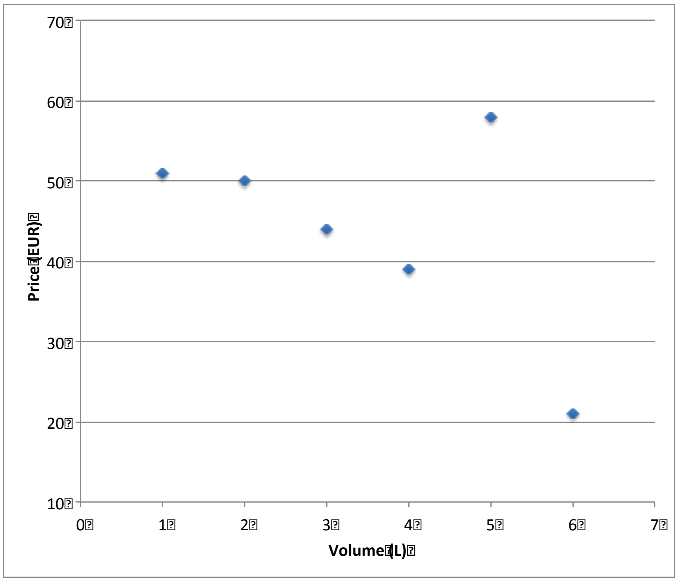

Figure 6 Volume versus price of rice cookers
*n=1276

However, there is no obvious pattern in figure 6 for the rice cookers. The price decreases with the volume range from 1 to 4 liters, and then the price jumps and falls without any regular pattern. The average of 5 liters rice cookers is much higher than the other liters. The number of models at 5 liters is 324. Under the same volume, the price differences are so huge that it can be said the volume has very limited impact on the price. The average price of all rice cookers is about 47 Euros, but the standard deviation is high, up to 70 Euros. There are very cheap rice cookers for basic cooking and there are extremely expensive rice cookers with complicated functions for multiple cooking. There are also a lot of imported rice cookers whose prices are much higher than domestic products.

As the price increases with the capacity, the subsidy criteria are increased with the capacity in the rebate programs. The higher the capacity, the higher the subsidy. However, the subsidy should not be awarded to the oversized products, because the ratio between the subsidy and retail price decreases with the capacity. The low subsidy ratio has limited impacts on switching the consumer's preference towards the high efficiency products. It might also encourage the consumers to buy larger products, which they don't need. No matter what, the efficiency changes with the capacity, the absolute energy consumption increases with the capacity [3].

Impacts of energy efficiency tiers on the retail price

Energy efficiency tiers play key roles in the policies. Tier 3 or 5 are the mandatory minimum requirements for products to access the market. Tier 2 and 1 are generally endorsement requirements for the energy efficient product certification and incentive policies. Energy efficiency tiers also have impacts on the product prices.

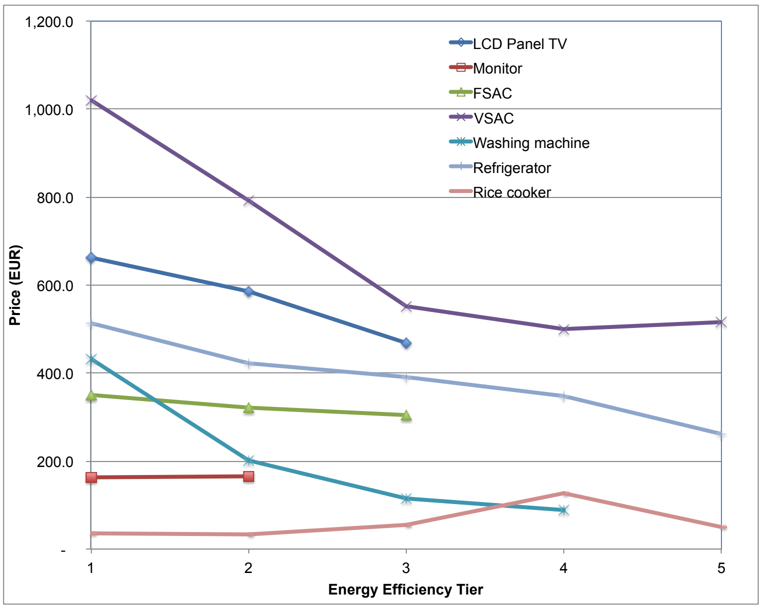

Figure 7 Energy efficiency tiers versus average price of 7 selected products
*n=9847

Figure 7 shows that the price has very close relation to the energy efficiency tiers for 5 products, with the price increasing with better tiers. The similar relation of price and energy efficiency tiers can be observed in Europe [19]. For rice cookers, the price is not related to the energy efficiency tier. Some low tier products even have much higher purchase prices than high efficiency ones. The price of tier 4 is very high, because most of the tier 4 products are the imported multi-functional rice cookers. The quality and other factors play a more important role in the product pricing than the energy efficiency tier.

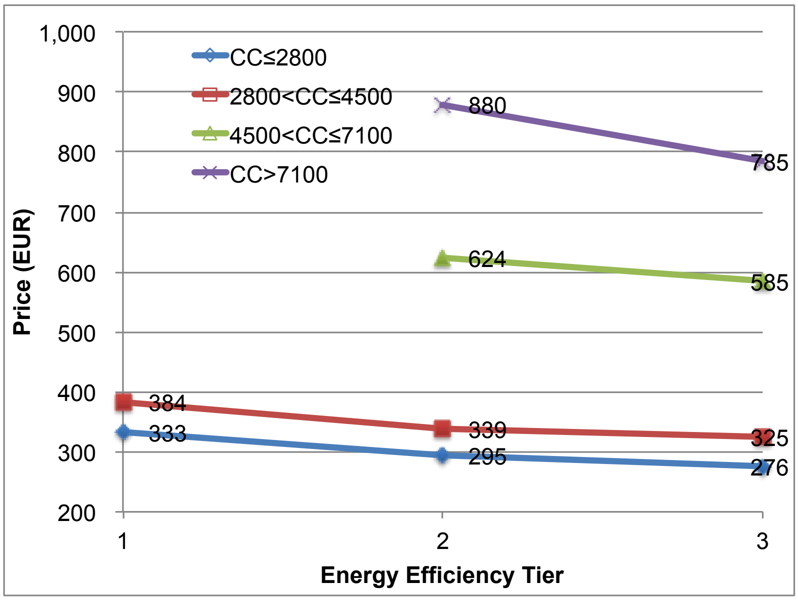

Figure 8 Energy efficiency tier versus price of fixed speed air conditioner
*n=1714
** CC = Cooling Capacity, Unit: W.

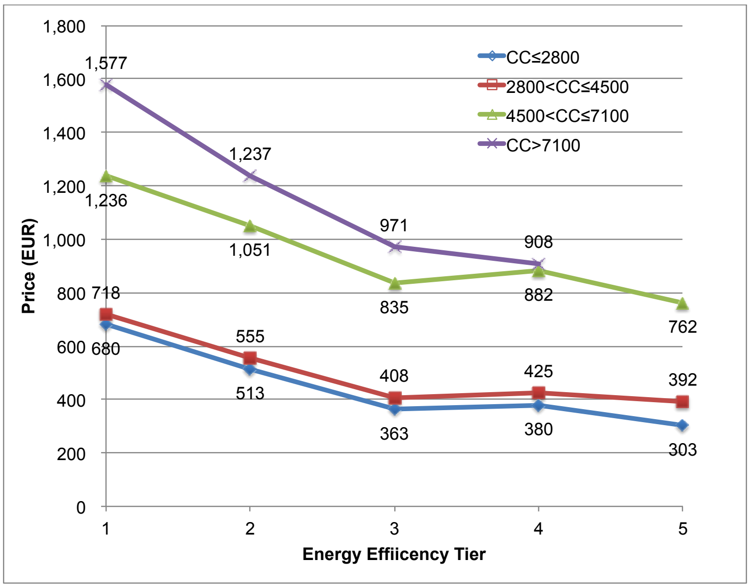

Figure 8 Energy efficiency tier versus price of variable speed air conditioner
*n=915

Generally, the manufacturing cost of the high energy efficient products is higher than the low efficiency ones. For the variable speed air conditioners, the price differences between tier 1, 2 and 3 are so significant that one can deduce that manufacturers and retailers develop their product pricing strategy according to energy efficiency tiers (and not according to the actual added cost of better equipment). The life-cycle cost of the higher tier products is also higher than the lower tier products, which means that the users can get the extra purchasing cost back from the energy saving [20]. Further research on the manufacturing costs, retail price, energy efficiency and market competition should be conducted for those products.

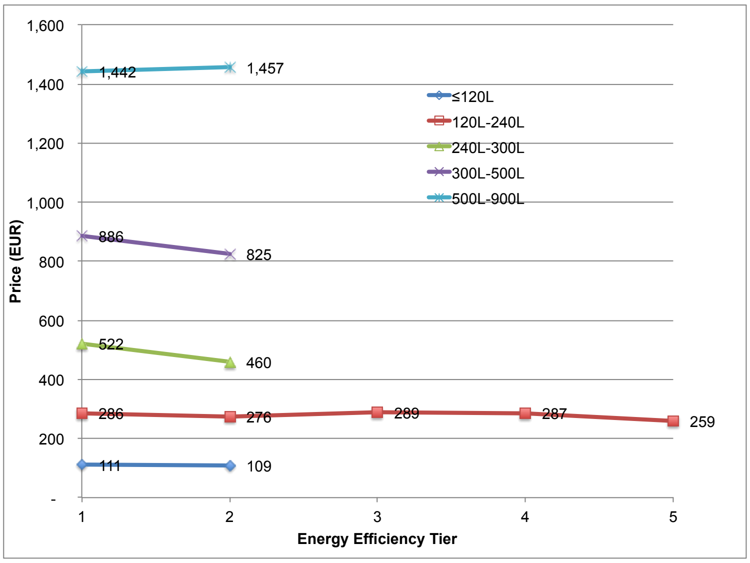

Figure 9 Energy efficiency tier versus price of refrigerators
*n=1667

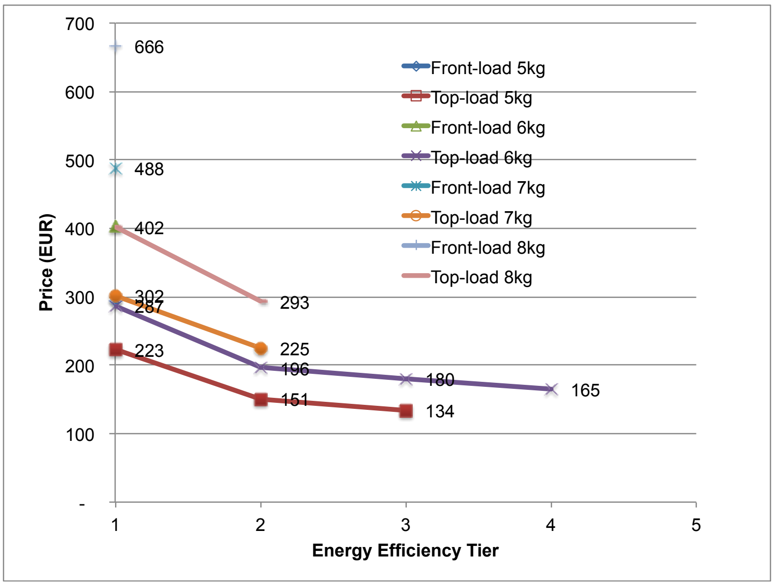

Figure 10 Energy efficiency tier versus price of washing machines
*n=1163

A similar relationship between the energy efficiency tier and price can be found for the refrigerators. In general, the price increase with better tiers. However, for the rice cookers, the price has no correlation with the energy efficiency tiers.

Impacts of energy efficiency indicator on the retail price

The energy label also discloses the energy efficiency indicator information. It provides further information for the consumers to compare the products within the same energy efficiency tier. Because there are too many products, tier 1 products for the refrigerators, washing machines, panel TVs and monitors [3][20], the detailed efficiency indicator information is the only source to distinguish the products. However, more than 58% consumers don't understand the energy efficiency information on the label [8].

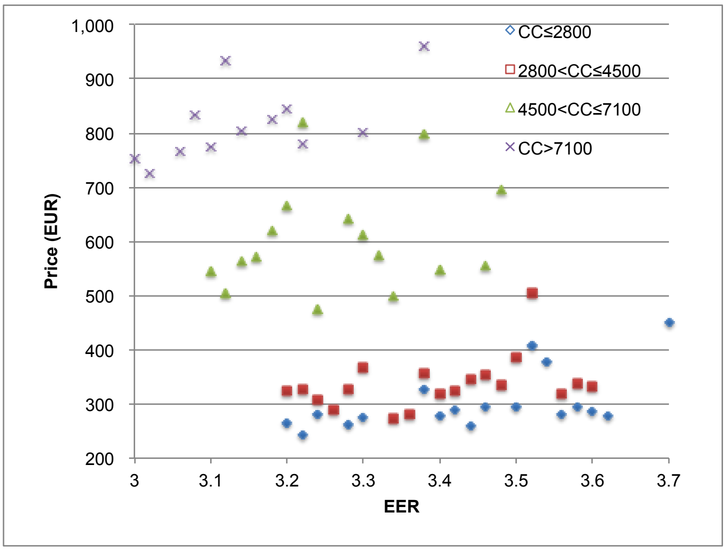

Figure 11 EER versus price at different cooling capacity range of fixed speed air conditioner
*n=1714
** EER : Energy efficiency ratio

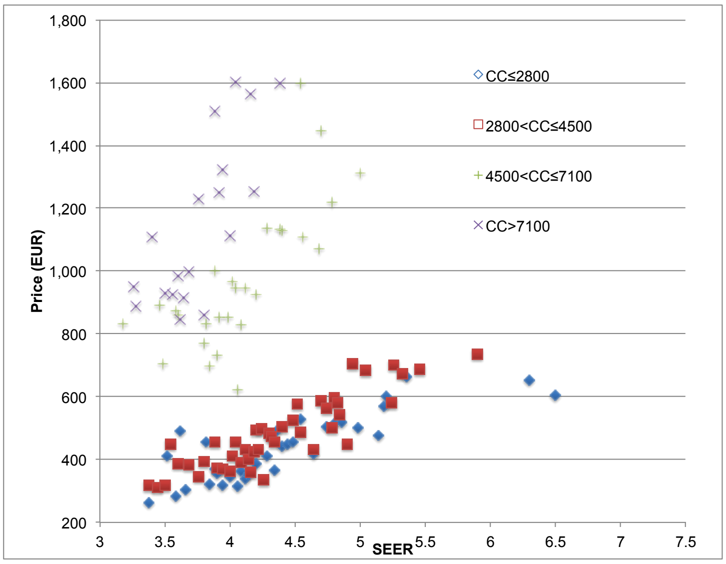

Figure 12 SEER versus price at different cooling capacity range of variable speed air conditioner
*n=915
** SEER: Seasonal energy efficiency ratio

For the fixed speed air conditioner, the price has a clear changing pattern with the EER. However, for the variable speed air conditioner, the price increases with the increase of SEER in four categories. The fixed speed air conditioner has the scale of 3 energy efficiency tiers, while the variable speed air conditioner has the scale of 5 energy efficiency tiers. The tiers might help to regulate the price with the SEER. The consumers also pay more attention to the energy efficiency of air conditioners [8].

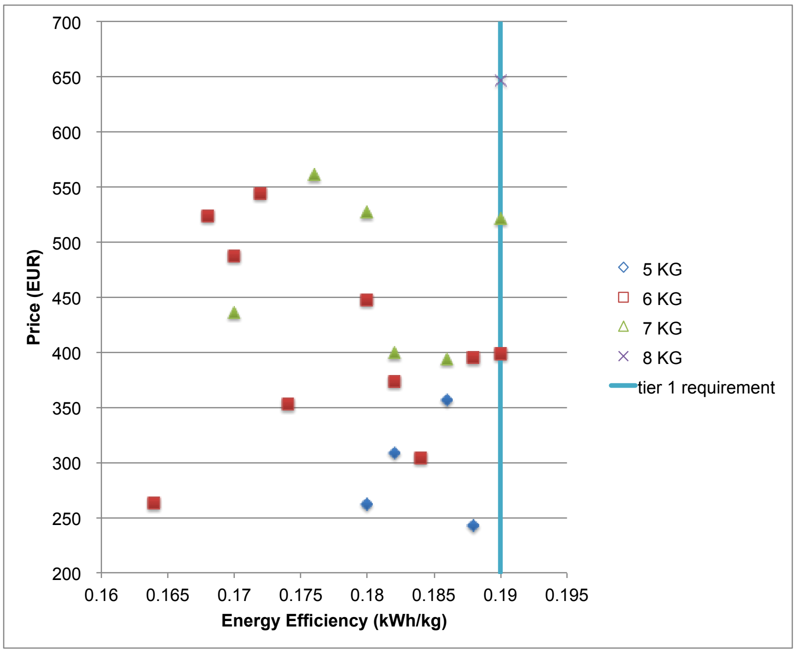

Figure 13 Energy efficiency versus price at different washing capacities of front-load washing machine
*n=428

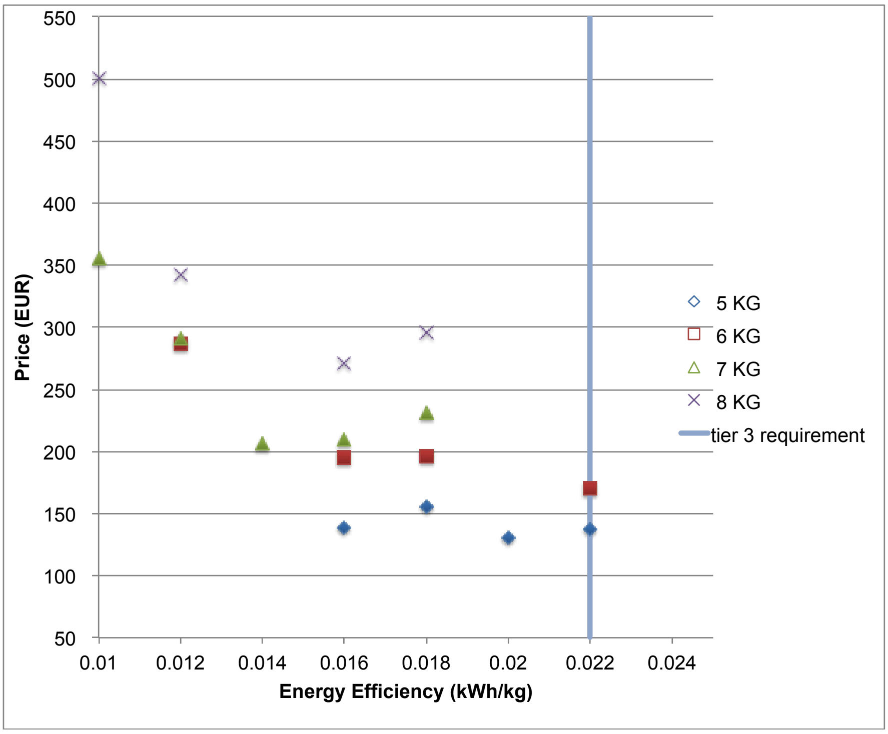

Figure 14 Energy efficiency versus price at different washing capacities of top-load washing machines
*n=735

All front-load washing machines are labeled under tier 1. In this situation, only detailed energy efficiency indicators could be used. However, no patterns can be observed from Figure 13, which indicates that the efficiency indicator information does not affect the price.

For top-load washing machines, the general pattern is that the price goes down as the energy efficiency decreases. There are 3 energy efficiency tiers for the top-load technologies. The similar phenomenon can be found for the water efficiency of front-load and top-load washing machines.

There are also no patterns between the price and energy efficiency information for the flat-panel TVs and rice cookers.

For most of the products, the energy efficiency indicator information has very limited impact on the price, because it's not easy for normal consumers to understand the technical background of the efficiency. Taking the flat-panel TV for example, the efficiency indicator is named Energy efficiency index (EEI). It's the ratio between luminance and power in principle. However, it's corrected by a factor according to the technologies (LCD and PDP). It can't be expected that the consumers will fully understand what the EEI represents. They can't compare the products according to the EEI. It's well known for them that the lower of the energy efficiency tier, the better the efficiency. However, for most of the energy efficiency indicators, the higher the value, the better the efficiency.

Conclusion and recommendations

1. The technology has great impacts on the price. The new technologies bring new improvements, not only the energy efficiency, but also other features such as user experiences and shape, etc. All the improvements are jointly affecting the price. Generally, the new technology has a higher price than the older technology. The price of the new technology goes down when the new technology takes a bigger market share. The rebate program should help the technology with the highest energy saving potential to penetrate the market, and the subsidy should not be awarded to the low efficient technologies, such as

PDP TVs. This will accelerate the progress of the market transformation towards higher efficiency.

2. For most of the products, the price increases with the capacity. The subsidy criteria also increase with the capacity in the rebate programs. However, the absolute energy consumption increases with capacity accordingly. The subsidy for the large products might encourage the consumers to buy over-sized products they don't require. Not only the efficiency, but also the sufficiency should be taken into consideration in the rebate programs.

3. The price has close relationship with the energy efficiency tiers for most of the products, which increases with the better tiers. It's certain that the manufacturing cost of the high efficiency products is higher than normal products. However, for some products such as variable speed air conditioners, the price differences among the tiers is so high that it is possible to say that the manufacturers or retailers boost the price according to the energy efficiency tier.

4. Except for air conditioners, the price has low relationship with the energy efficiency information. The consumers lack in knowledge to fully understand the energy efficiency indicator. The public education of the energy label and reform of the energy label are needed.

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Understanding the consumer perspective: product solutions to enable and inspire consumers

Abstract

According to the European Environmental Agency report in 2012 “Climate change is occurring globally and in Europe it can increase existing vulnerabilities…”. Preserving the environment is a shared concern, but individuals do not consistently make sustainable choices: faced with 2 alternatives they maximize their benefit, responsible choices are possible when individuals are given a credible option where societal good is not completely opposite to their own.

To foster a sustainable behavior both rational and moral drivers must be leveraged. The rational drivers are addressed by devising mechanisms that realign personal benefits with societal benefits; while moral drivers can be reinforced by awareness and social feedback, both approaches taken singularly have their limits but well combined they can reinforce each other.

Appliances have done outstanding developments in improving their energy efficiency due to past progress the physical limit is approaching, further improvements come at greater costs and without a technology breakthrough they may be minimal. However an untapped potential still lays in users habits: this comes in energy saving potential and energy usage shifting potential. Both can be still helped by technology, but the human factor and motivation must be considered.

Indesit would like to reap the energy saving potential by exploring ways to give feedback and improving consumer awareness and it has thus started a field test aimed at understanding how feedback can help consumers.

Indesit believes that in the future flexible consumers who adapt their energy consumption to low time tariffs or green energy availability will contribute to the sustainability of the power grid, however a strong economic incentive is needed to pull enough flexible consumers which can make a difference.

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Main topic : Smart Appliances, Home Automation, Smart Homes, and Smart Grids

Keywords: Consumer Behaviour, appliances, energy efficiency, demand response, feedback

Where Europe goals are not aligned with consumer drivers policies are difficult to implement

The skiing chairlift problem is a typical example of detrimental collective behavior stemming from a misalignment of drivers. After waiting in line for 15 minutes one seat is available in the next chair, will you leave your family behind and fill in the available space? Filling all the seats to reduce everybody's waiting time would be a rational behavior, but people usually don't take up the seat regardless the length of the line: in this case the perception of the link between collective waiting time and singular behavior is not strong enough to motivate an altruistic choice. In this example moral drivers could be stimulated by signs asking to fill in the seats, while rational drivers should be created by an improved organization like a fast line for single skiers. Rational drivers are naturally more motivating, moreover the presence of rational drivers usually indicates that a system provides for a fair sharing of rewards, they should be the first solution to explore before resorting to moral drivers. To tap the improvement potential that lays within consumers this human factor needs to be considered: people need incentives and enabling solutions, on top of information.

Energy prices schemes and consumer motivation

While the EU Commission asks Member States to ensure timely feedback for consumers and asks utilities to save 1,5% in final energy consumption each year, competition has brought some utilities to offer fixed monthly rates in order to retain consumers. Energy price is an enabling driver to reduce energy consumption however energy prices cannot be increased without hurting vulnerable consumers. There appears to be no easy solution to this issue: the price driver alone is not enough to motivate consumers to change their behavior: reduce their comfort and spend less; however the price driver, coupled with the moral driver of sustainable behavior and enabling technology, can bring consumers to reduce energy consumption if convenient solutions are presented to them.

If the energy price has a limited potential in reducing total energy consumption, its possibilities in profiling and shaving peaks are still largely untapped. Many sources point to the need to shave peaks in order to optimize investment in infrastructure while guaranteeing security of supply, in a system that depends increasingly on renewable stochastic and non controllable sources like wind and solar energy. The Energy Efficiency Directive (EED) calls for Member States to remove the obstacles against offering time of use tariffs, and the Commission in their “Communication on making the internal energy market work” asks that consumers are given the advantage of low tariffs in low demand periods and says “Even if regulated prices allow the cost of operations to be covered, they do not send the right price signals needed to secure efficient investment” [3].

Unfortunately in some countries in Europe the possibility to set effective time of use schemes is hampered by the heavy taxation on energy prices, taxation is a flat component which attenuates the price component. Revision of such tariffing systems is both a matter of energy regulation and taxation. Such a revision is now required by the EED, which Member States must transpose into national legislation by June 2014. Past experience with time tariffs shows that a real economic convenience coupled with an understanding of consumer experience are needed to change consumption profiles, so the possibility to spur the flexible demand resource depends on the tariff schemes that will be enabled and on devices that will facilitate it.

Economic advantage of time tariffs

The EED calls for flexible demand to be rewarded in a non discriminatory way and this entails a market where flexible demand can participate as a resource. Renewable energy sources are challenging grid management in many EU countries: as the EU shifts to solar and wind power, it also needs to change its energy consumption paradigm by adapting consumption to production patterns rather than the other way around.

In an ideal market flexible consumers, which accommodate their demand according to the available production, should see a marginal price of energy approaching its marginal cost. Renewable energy sources on which Europe is increasingly relying, at times produce excessive energy, then its real marginal cost becomes negative. Consumers who choose to start the washing machine only in these time periods should not pay for the energy consumed. If the market were allowed to work, the incentive for managing demand would be very effective: as long as there is temporarily excessive energy from wind and photovoltaic sources a totally flexible appliance should have free energy. In practice the market cannot be totally free since one should consider the cost for ensuring consumers against the risk of very high tariffs in moments of peaking marginal prices; still the opportunities for energy market efficiency and filling those chairlifts are still promising.

Engaging consumers while solving their problems

Engaging consumers into energy efficiency means both providing a moral motivation and a rational edge, household appliances can help by increasing consumer awareness on their consumption, provide energy saving advices where and when they are needed and making it all easy and fun. For household appliances manufacturers the challenge is threefold: developing new technologies, building new business models and strategic alliances, and understanding how to deliver tangible benefits to consumers.

As a way to address these challenges Indesit has been among the founders in of Energy@home association bringing together appliances manufacturers, utilities, telecommunication and solution providers to explore smarter ways to use energy while guaranteeing performance. Energy@home is a non-profit association registered under the Italian laws with the purpose of developing & promoting technologies and services for home energy efficiency based upon device to device communication. Founded in 2012 by Electrolux, Enel Distribuzione, Indesit Company and Telecom Italia, the Association now counts among its members also: Edison (energy retailer), ST Microelectronics, Vodafone, Whirlpool, while several technology providers count among its aggregate members[1]. It thus brings together a wide range of competencies to develop energy services in the residential sector.

Figure 1: Members of the Energy@home association

At the end of 2012 Energy@home has launched a trial of its services with the intent to understand the human factor: how people consume energy, the variability in consumption profiles, improvement potential, and consumer reaction to feedback. It was not possible in this trial to explore consumers flexibility and the potential for demand response, because energy regulation in Italy does not yet enable retailers to set dynamic time tariffs. However some sources also point to the importance of

[1] ICT (Altran Italia, Intecs), microelectronics Freescale Italia, inverter and storage (Power One), research institutes (Istituto Superiore Mario Boella) and other technology MSE (Fly-By, Flexgrid, Eurotherm, MAC, Gemino).

understanding consumers and make them aware of their energy consumption patterns before exposing them to dynamic tariffs [6]. 20 out of the 50 users had solar panels and therefore an incentive to use energy when they have own production.

Consumer awareness applications

The field test was launched in 50 homes in a town of central Italy in a rather homogenous social context. The consumers form a community of early testers as such they receive social feedbacks relating anonymously to the other participants. The project will last 3 years and is aimed at understanding which information are more useful, how they should be delivered and how consumers use feedbacks.

The field test deploys smart appliances, smart plugs to monitor energy of non smart devices, an interface to the digital meter, an in home gateway, and a PC user interface.

Figure 2: devices in the Energy@home field test

The smart appliances can estimate their power consumption and send the information to the home gateway which processes it and makes it available on the user interface. The system gives information on the best timing to use appliances, this is relevant for those consumers which have solar panels and can choose to use own energy rather than purchasing from the grid.

Figure 3: user interface of the Energy@home monitoring interface, it shows instantaneous, daily consumption, comparison with the average user, single appliances power consumption and expense by energy consumption.

These devices allow to provide targeted and social feedback to consumers. The following graphs show an example of the information which can be provided to consumers. From the small sample in the geographic area large differences are already visible. These differences are particular interesting since they indicate the improvement potential.

In [13] the relationship between energy uses in households and the behaviour of end users is discussed highlighting that two categories of determinants can be settled as influencing electrical consumption in residential buildings:

Behavioural determinants, involving "flexible" decisions where the energy-use is strongly correlated to household human factors, such as people habits, daily routine and needs.

- Physical determinants, involving "fixed" decision where, on the contrary, the energy-use is correlated with the number of occupants, the climate and building design, while it is low correlated to human factors.

Figure 4 shows the weekly energy consumption of a sample of 10 families in the same geographical area where the picture on top of each bar reports the family size. It is immediately evident that there is very small correlation between the energy consumption and the family size while the difference in consumption is mainly due to the difference in the occupant behavior, i.e. the behavioral determinant part of the consumption. Considered that these families are not using electrical energy for heating and air conditioning, the difference in consumption cannot be ascribed, apart for a very minimal quantity, to difference in other physical determinants such as the dwelling size, or the building design and energy efficiency.

Figure 7 shows the stand-by power measured in the same sample of 10 families, the so-called "vampire power" of the house that is that minimal electrical absorption that is constant over the 24 hours of the day. Even in this case there is a strong difference between the 10 families with two families having a stand-by power of more than 120 Watt which results in an electricity bill of about 200 €/year due only to the stand-by of the household appliances!

Figures 4 and 7 were sent by e-mail, as a newsletter, to the users of the trial as a persuasive stimulus to motivate to change their behavior. Following these information consumers were also instructed on how to use their system to check which devices are responsible for the standby power consumption.

Figure 5 reports the average weekly energy consumption measured before and after sending the newsletter. The results are very preliminary as they refer to just 10 families and as such they require proper attention and discussion. In fact, on average a reduction in energy consumption of 16% was measured but it must be considered that the newsletters were sent in March when there is a seasonal change that it is well known to impact the residential energy consumptions. In order to get more information useful to this analysis, we also measured the reduction in stand-by power after sending the newsletter: on average users reduced stand-by power by 12%, with 3 users reducing by more than 10 Watt and one user reducing by 77 Watt. The saving in stand-by of this user will result in an annual saving in electricity bill of about 120 € and it accounts for more than an half of its energy saving reported in Figure 6!

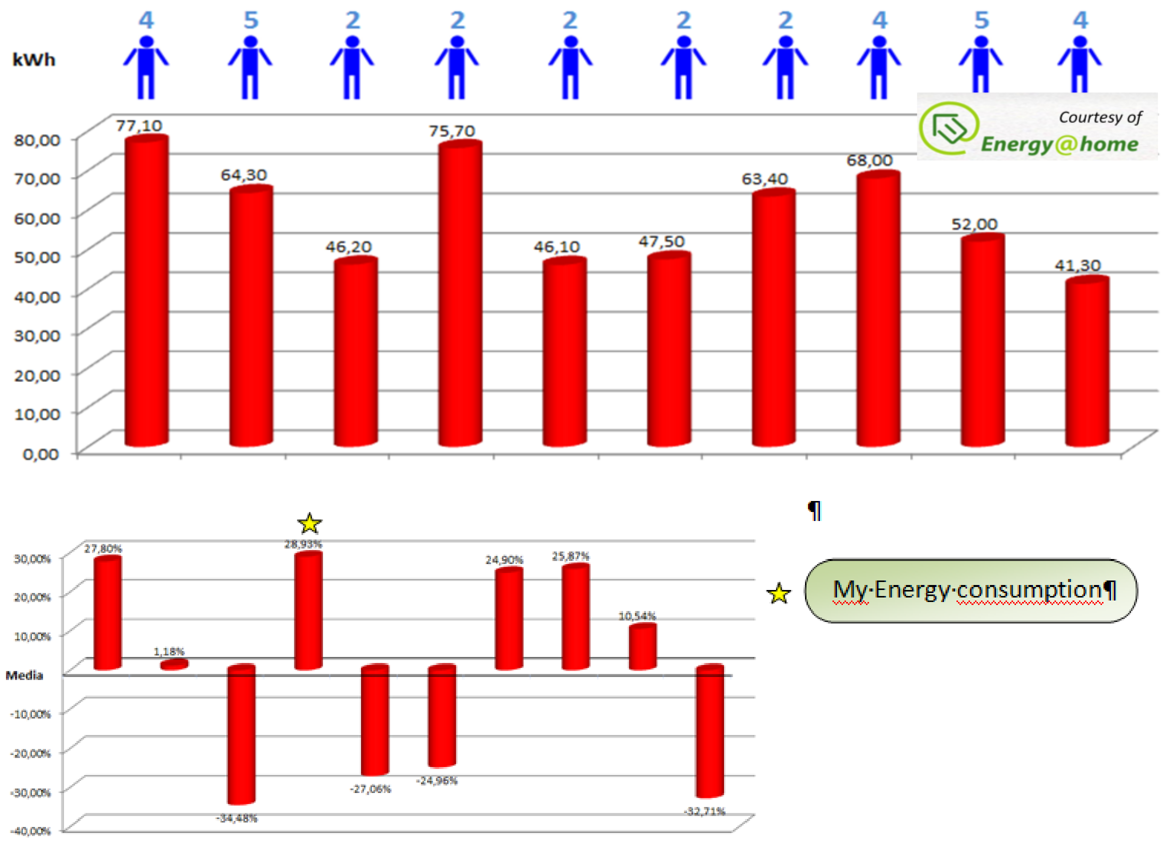
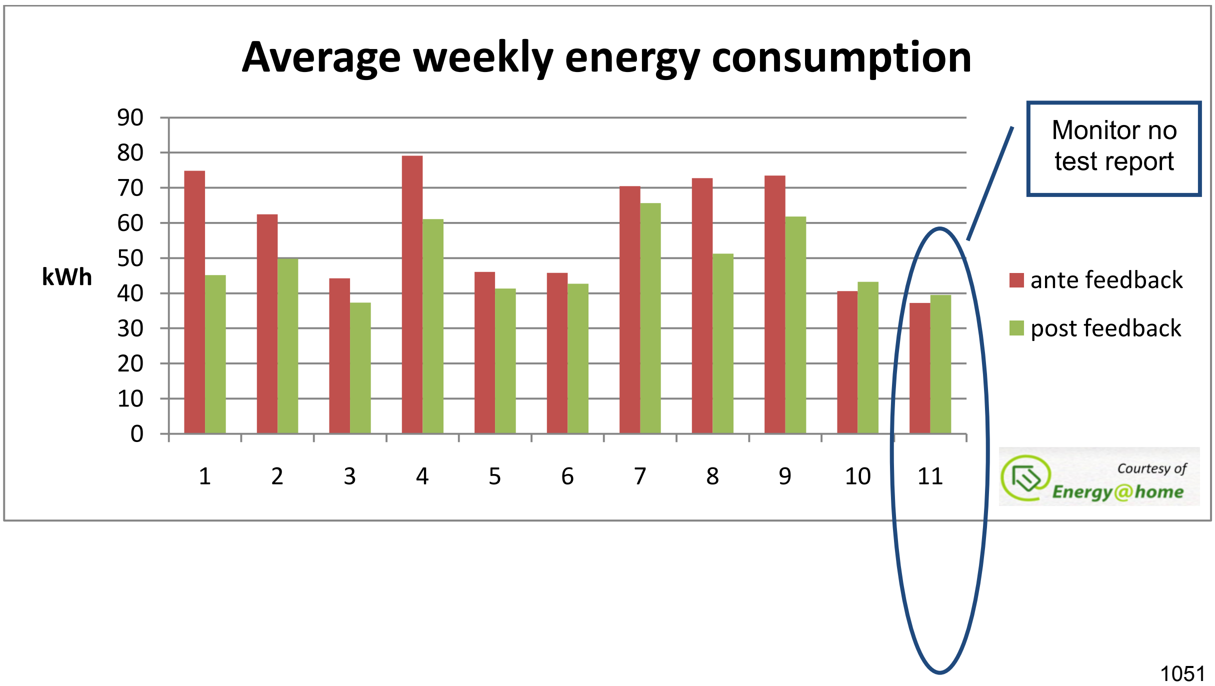


Figure 4: Social feedback weekly energy consumption compared with community average



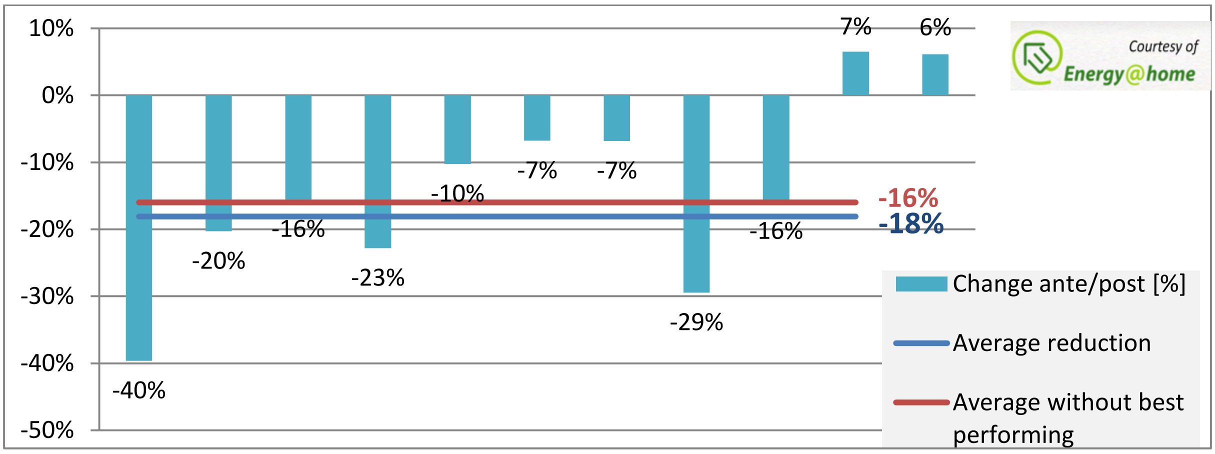


Figure 5: energy saving following email notification with social feedback, data not cleaned by seasonality effect

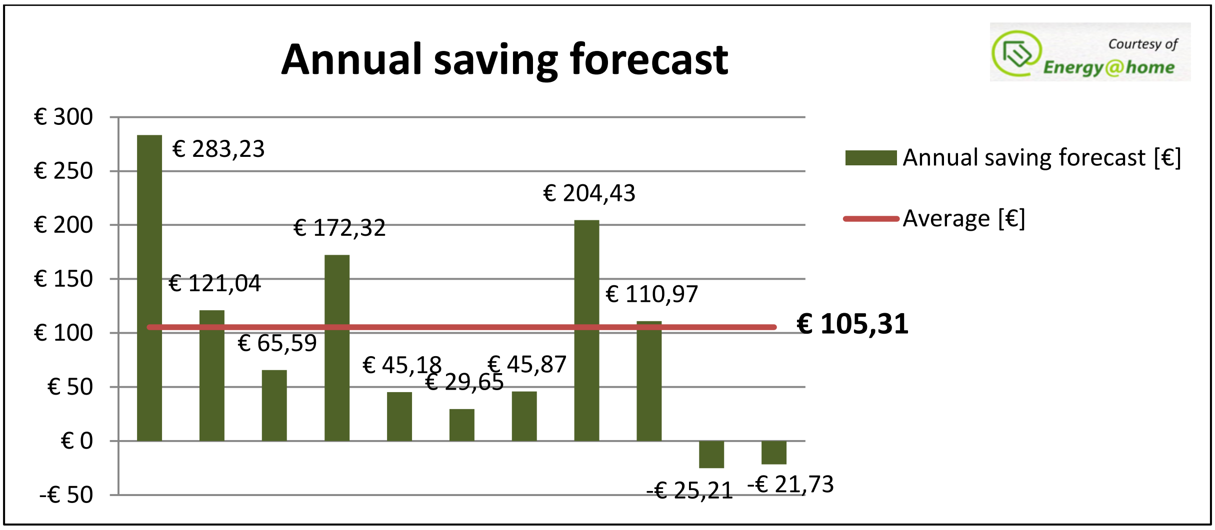


Figure 6: saving forecast after receiving social feedback, data not cleaned by seasonality

By detecting the minimum value of power consumption throughout the day, consumer can be made aware of the hidden power consumption of standby. In some cases this was so high as 120 W. Following these information consumers have been instructed on how to use their system to check which devices are responsible for the standby power consumption.

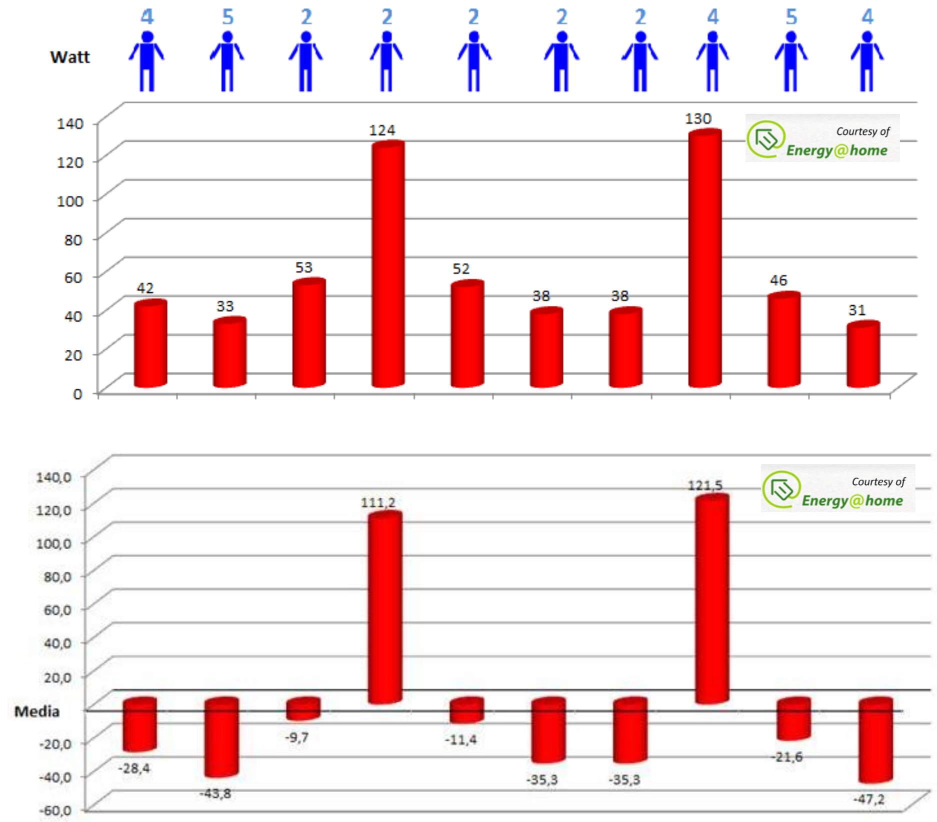
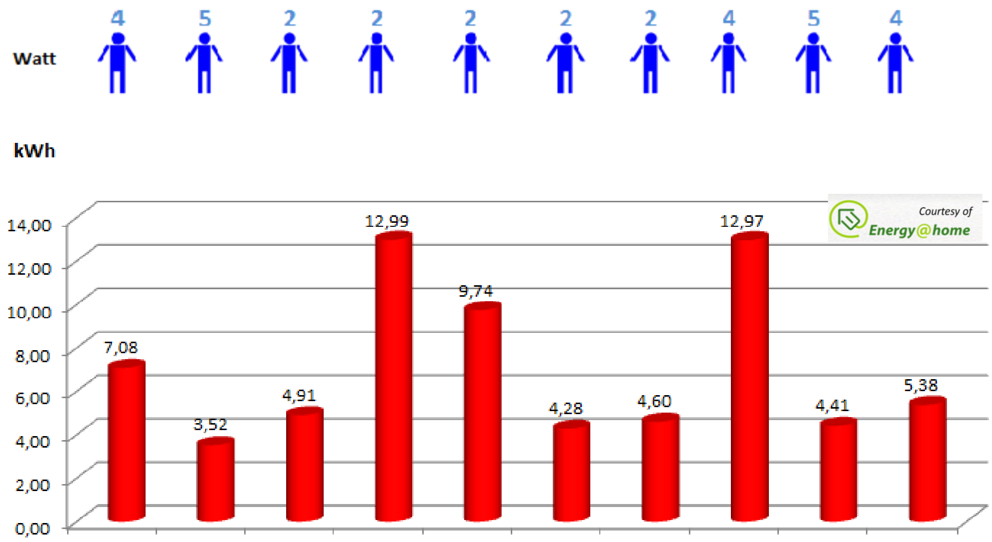


Figure 7: Social feedback minimum energy consumption as a proxy for standby compared with community average

The smart appliances can provide specific information about how they are used and the impact on energy consumption. For washing machines it is possible to inform consumers about the average power consumption of each cycle, about which programs they are using most and how much they are loading their washing machine compared to the rated capacity. Consumers have also been able to learn how much their refrigerator is consuming, this is a valuable information to better plan the purchase of a new refrigerator, or simply to adjust appropriately the temperature setting.



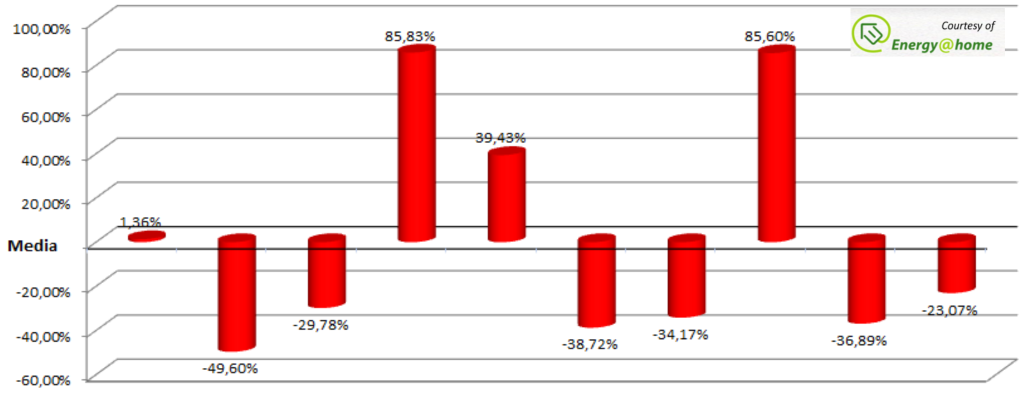


Figure 8: Weekly fridge energy consumption

By deploying smart plugs it is also possible to inform consumers about which devices are the most energy consuming; this is valuable information since each household is different in this regard: it is often but not always the fridge.

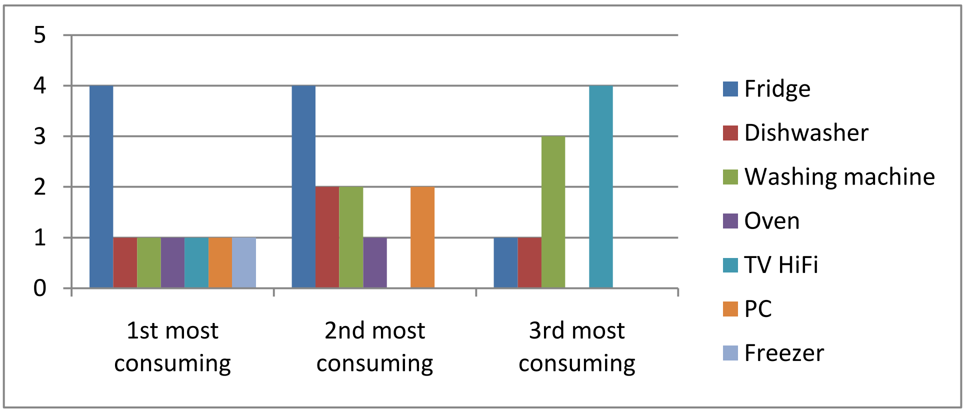


Figure 9: how often an appliance ranks in the most consuming 3

Even if the first 3 devices change and sometime include also TV and WiFi or the PC, the quota consumed by the first 3 is usually over 40% of the total consumption.

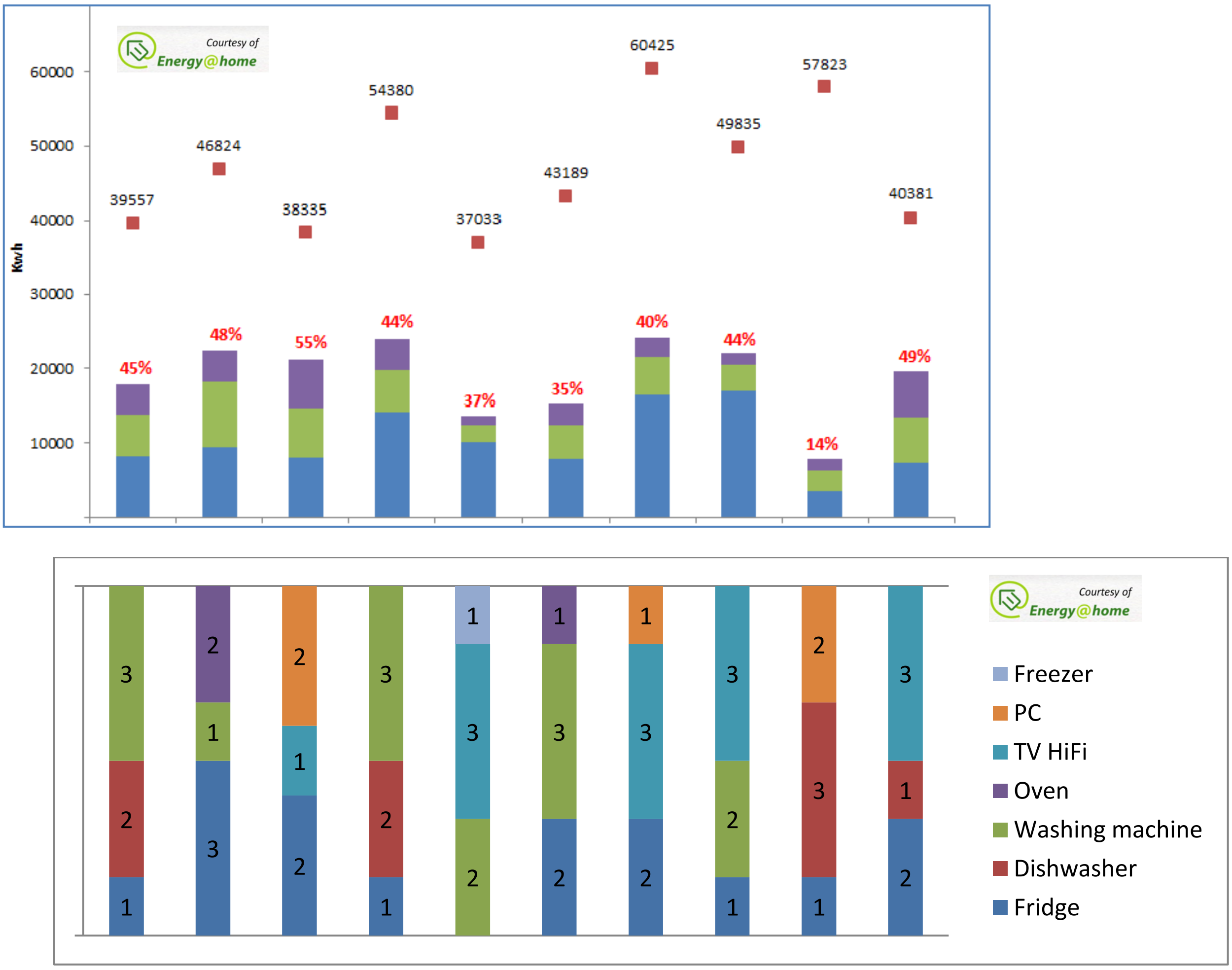


Figure 10: % of total energy consumed by the first 3 devices

After 2 months of monitoring consumers were asked to rank the features of the system in a scale from 1 to 10, the picture below reports the top 5 features:

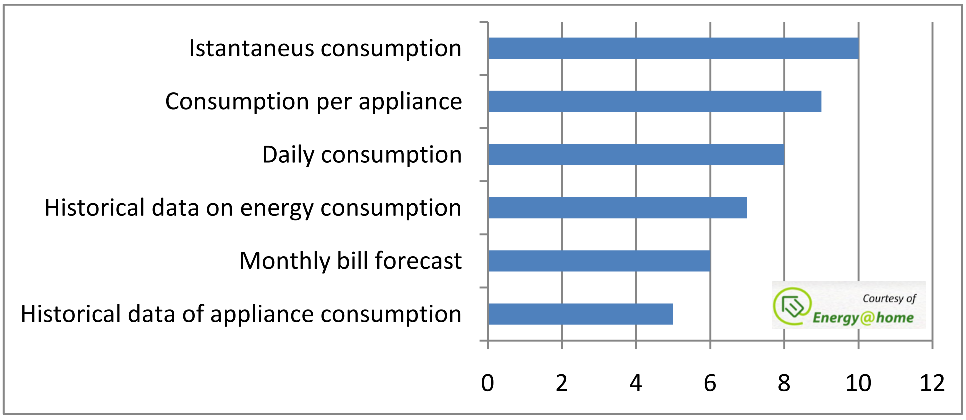


Figure 11: Consumer ranking top 5 features

By end of July the installed sample has been increased to 50 households, which will be monitored for the next 3 years. One of the objects is to observe if consumers starting with a higher energy consumption can take on energy saving habits or switch to more efficient appliances, differences in initial levels indicate that there is a high potential for energy saving by addressing users habits.

Smart grid and demand response applications

Another high potential for appliances to support a sustainable behavior is by helping consumers participate to a demand response scheme and take advantage of lowest time tariffs.
Appliances of the Energy@home test are already capable of planning their start time based external signals from the grid. The appliance can minimize user inconvenience by ensuring to meet the requested delivery time within a flexibility period, however the current tariffing schemes in Italy do not provide any incentive to do so. A new version of the Aqualtis washing machine can inform consumers about the energy cost of the selected options and program and informs consumers about the best time to start based on time tariffs or renewable energy availability. In addition to the information on the appliance, Indesit provides an application for tablet or PC allowing consumers to easily simulate the cycle cost and energy consumption and see varying the different options can affect it. It is thus possible to provide advice on the best spinning speed depending on the post washing treatment. The interface allows also remote monitoring of the appliance.

Figure 12: appliance consumption simulator on Indesit E@H application

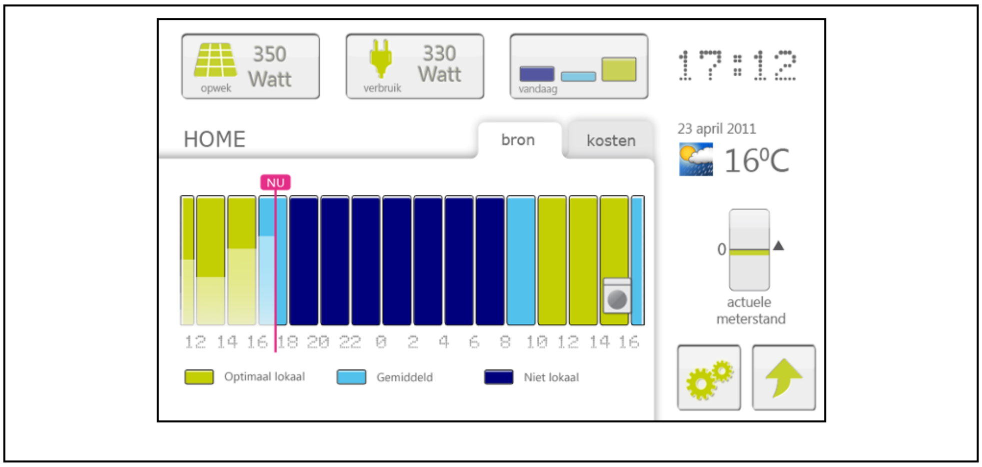


Figure 13: : helping consumers use their appliances when renewable energy from solar panels is available, field test trial of Enexis and Indesit

Conclusions

Consumers will choose more sustainable ways to manage energy consumption and use appliances only if multiple conditions exist: there is a tangible benefit, the positive contribution to the grid is communicated in a clear and rewarding way, the user experience is positive: meaning performance and convenience of appliances should not be lower e.g. when operating in flexible mode. So smart grid ready washing machines are waiting for the time when more Regulators in Europe will allow tariff schemes which reward flexibility as the Energy Efficiency Directive recommends.

The speed with which consumer will start participating in consumer awareness and demand response schemes will depend on the benefit they receive. In the case of demand response utilities are required to estimate the value of flexibility and devise appropriate tariffing schemes. The EED does state a fundamental principle: that demand response as a resource must be guaranteed a non discriminatory treatment in the energy market. Ultimately the savings consumers will be able to achieve will depend on the energy regulation and features of demand response programs. In particular features that affect the slice of value given to consumers are: possibility for consumers to opt out, possibility to bypass signals from the grid, possibility to retain own data or sell to the grid data which ones aggregated have an economic value.

Final entry barriers are another issue: the cost consumers are willing to pay for the enabling equipment is related to expected savings or to additional services for consumers which can be enabled by the same technical means.

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Waking up the dragon – Can energy efficiency induce new and more consuming lighting practices?

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Abstract

In the last four decades energy efficiency has become a central element of policy documents and public speeches. Success in promoting energy efficiency has been different across sectors. In households results are often more difficult to obtain and monitor.

A conjunction of factors related to agential powers and structural elements - lifestyles, information, education, social status, income, age, incentives, knowledge, technology, and infrastructure - seem to be shaping the way energy efficiency is being integrated in day-to-day practices.

Building on the theories of practice this communication aims to discuss the influence of factors like rules and knowledge, meanings, material structure and practical understanding in shaping lighting practices among Portuguese families and how energy efficiency has influenced the way people understand lighting as a practice.

Results show that, at the same time as energy efficiency became a central element in policies for the lighting area, diversification of solutions introduced new choice factors that made more complex the once simple act of acquiring a light bulb. Also partially due to the diversification of lighting solutions, changes have occurred on the cultural meanings and functions attached to lighting practices. This new context has resulted in the construction of new practices related to lighting, not necessarily more efficient or sustainable.

Combining data from a survey and interviews to families and to energy experts and technology manufacturers, different perspectives will be discussed aiming at a deeper understanding of the pros and cons of energy efficiency if the objective is to build a more sustainable society.

Introduction

Ever since de 70's energy efficiency became a central element of public policies for the energy area enacted by the European Union. From a context where member states maintained full control over energy policy, a clear evolution occurred that resulted in a progressively stronger EU role.

But at the same time as this evolution occurred, based on the increased awareness of the centrality of energy and its efficient use for EU to achieve a sustainable development, a quieter change was also occurring. Public policies aimed at influencing households and families to use energy more efficiently were developed and implemented over several decades. Such policies usually implied that if citizens or families were empowered to use energy more efficiently, using information and making technological solutions available, sooner or later results would appear. But such a direct effect, except in some specific contexts, has shown to be elusive. It is true that at present, in the EU, energy is used more efficiently, but results are far less significant than could be expected, if assumptions backing public policies, namely those referring to the main barriers to be overcome, were the only variables to take into account.

The not so interesting results have open the door to disciplines like Sociology to try to contribute to a broader understanding of what, in fact, can induce social change and can influence practices involving energy use. And for that to be possible, we have to go beyond the usual suspects – agents and barriers – and integrate a broader context where public policies and technology development are scrutinized not only in their intrinsic capacity to promote a more efficient use of energy, but also, on how they can induce more energy consuming practices, for example, by standardizing and legitimizing certain energy consuming practices.

In this article, our aim is to illustrate this complexity using the example of lighting practices. For that we will use practice theory, which by integrating agential and structural factors, allows us to analyze the interplay between these two dimensions and how they contribute to more or less sustainable practices.

For this article we use data gathered for the author's PhD thesis. Due to the field work time frame, CFL was the only lighting technology available in a large scale for households. For this reason, Led Technology was not included.

The theory of practice and the analysis of lighting practices

Theory of practice emerged as a theoretical orientation that brings together a wide range of approaches that seek to overcome the classic division between agency or structure as the defining element of human conduct. The innovation of these approaches relates to the capacity to:

> "(...) explaining and understanding actions by reconstructing the symbolic structures of knowledge which enable and constrain the agents to interpret the world according to certain forms, and to behave in corresponding ways. Social order then does not appear as a product of compliance of mutual normative expectations, but embedded in collective cognitive and symbolic structures, in a 'shared knowledge' which enables a socially shared way of ascribing meaning to the world." (p.245-246[1])

Theories of practice began to emerge in the 70s stimulated by authors like Pierre Bourdieu and Anthony Giddens, although the list of authors is extensive, as well as the interpretations and explanations offered [2] [1]. Despite this context, some of the authors who have recently focused on this topic and that have applied it to the area of consumption and energy identified a set of common concerns that constitute a way to address the social reality, namely, by underlining the significance of symbolic structures of shared and collective knowledge as a key element to explain and understand agency and social order [2] [1]. In short, theory of practice puts practices at the heart of understanding the social, where other theoretical approaches put agency, structure or language (p. 46 [3]) and seeks to give emphasis to the realm of the symbolic and cognitive exploring how these structures give meaning to the world in a contingent way [1].

Theories of practice aim to highlight that human subjectivity resulting from reflexive capacities and intentionality is closely related to how practices are structured and how they "co-constitute individuals and their values, knowledge and abilities" (p.815 [2]), underlining the importance of analyzing the direct relation between agential powers and social structure [4].

Schatzki defines practice as a nexus of actions and meanings that are connected by an understanding of what to say or do, by explicit rules, principles and instructions and teleoaffective structures, where purposes, projects, goals, beliefs and emotions come together [5]. This perspective implies the importance to analyze, not only the practical elements, but also social representations [6]. To Reckwitz a practice is "a routinized type of behavior which consists of several elements, interconnected to one another; forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge (p.249 [1]). That is, "a practice is thus a routinized way in which bodies are moved, objects are handled, subjects are treated, things are described and the world is understood" and it is social because it is a way of behavior and understanding that "appears at different locales and at different points of time and is carried out by different body/minds" (p.250 [1]). In this context, agents are carriers of bodily behavior patterns and of certain routinized ways of understanding, knowing and wanting, but these are necessary elements and qualities of the practice in which agents participate and not a quality of the agents. Therefore, practices precede agents, since they are a collective and historic event, that is developed through time by all those who get involved in that practice, and this reproduction is fundamental to keep the practice nexus and to guarantee its existence (p.134 [6]).

As for the identification of the key elements to understand practices there are different approaches. Alan Warde and Elisabeth Shove present their own interpretation resulting from the previous work of Schatzki and Reckwitz. For Warde practices present four key elements: understandings, procedures, engagement and items of consumption [6]. Shove and Pantzar [7] reduce to three elements, namely, competences, meanings and products. Kirsten Gram-Hanssen offers a slightly different perspective by highlighting the importance to distinguish between two types of competences: "know-how or nonverbal knowledge and explicit, rule-based or theoretical knowledge" (p.155 [3]), particularly when analyzing energy consumption. Since we agree with this perspective, lighting practices where analyzed using four key elements: practical understanding/embodied habits, institutionalized knowledge/rules, engagements/meanings and technologies/material-structures. Practical understanding or embodied habits refers to knowing what to do or how to react to a situation. In the present article we include in this element of practices the knowhow of families to choose lighting bulbs, to installed them and embodied habits of use. Institutionalized knowledge or rules can be understood as the set of conditions to decide which are the best lighting solutions or to interpret labels on light bulbs, for example. Lighting practices fulfill certain objectives or ends that can be both objective (for example when light bulbs are use to provide conditions to proceed with a certain task – like reading in the evening) or subjective (aesthetic value or comfort), and the meanings people attach to this practices play a role in structuring them. Finally we have technologies or the material structure that provides an important element of the practice. In the lighting area in the last few years important changes occurred not only due to the ban of certain lighting solutions considered to be least efficient, but also due to the increased diversity of lighting solutions offered.

Therefore, by combining these four elements and analyzing them when it comes to lighting practices, we try to highlight the importance to consider each element to understand a practice. By doing that we provide a different theoretical approach where agency and structure interact to structure patterns and practices, shifting the focus on individual choice to a broader approach where public policies and technologies are analyzed also by their "side effects" on "configuring the fabric and the texture of daily life" (p.1281 [8]).

Public policies regarding lighting

Policy action on energy efficiency has looked at lighting as an area for intervention. Seen by some as a way to force consumers to see beyond the initial price of the more efficient light bulbs and, therefore, aiming at promoting energy efficiency [9] and by others as a way to force transition and overcoming a technological "lock-in" thru direct regulatory action [10], the decision to ban inefficient light bulbs is one of the few times where public policies interfered with families context of choice in a very direct way. For sure many initiatives taken at the EU level influence solutions that are available to families, but usually that happens upstream and the final consumer doesn't realize that, for example, the washing machine he is about to buy has to have an energy efficiency above a certain level or otherwise cannot be place on the market. But it is still a washing machine that requires no especial adaptation of routines. The ban of some light bulbs has introduced a certain degree of complexity that did not exist before. Besides the end of life problem posed by compact fluorescent light bulbs – CFLs - (presented as the main alternative to the inefficient light bulbs that were banned), choosing a light bulb became increasingly difficult because new variables were introduced. Are we buying a lamp with 'cold' or 'warm' light, are they suitable for the fixtures and lighting appliances at home, are they compatible with dimmers, are they reliable and how long will they take to achieve full brightness?

During this transition period, several factors influence the acquisition and use of efficient lighting solutions, especially CFLs. The main barriers seem to be: waiting until there is a need to replace an existing light bulb and the light bulbs technical features – color, response time, suitability regarding fixtures and lighting appliances and cost [11] [12] [13] [14].

The social practice of household lighting can be understood as involving three dimensions: "the acquisition, installation and the use of lighting technologies" (p.224 [15]). In each of these dimensions there is space for large discrepancies in energy use depending on the type and number of lamps, how they are used and for what periods of time. Some of the differences that can be observed may be explained by cultural differences, as has been shown by Hal Wilhite in his comparison between the Norwegian and the Japanese lighting culture [16]. But within the same culture differences can be significant and despite the penetration of more efficient lighting solutions, some studies highlight that energy consumption for lighting continues to increase, at least in some cultural contexts [15]. When we analyze the EU as a all, data points in a different direction, showing some improvement in energy consumption mainly due to the introduction of more efficient solutions (p.73 [17]) and the same trend can be found in countries where *per capita* energy consumption has been stable for many years [18].

Nevertheless, some of the trends highlighted in the Crosbie and Guy study can be found among the families interviewed for the present study, especially when asked to compare their present situation with the past. The increasing number of lamps that are used is a common trend and seems to result, not only of the tendency to live in larger houses, but also of the passage from the single ceiling lighting to a more diverse set of lighting solutions that, in some cases, go beyond functional use to respond to an aesthetic or comfort objective (although among the interviewed families the use of new lighting functions tends to be very carefully framed and justified, as we will see later on).

But at the same time as strong public policies are being implemented with the aim of increasing lighting energy efficiency, the image that is being conveyed by the media and particularly by some design and decoration experts or even by manufacturers doesn´t always associates glamour, comfort and fashion to the most energy efficient lighting solutions. That is why some authors highlight the importance of working with different experts and at different scales in order to build an appealing image around solutions that represent sustainable forms of lighting [17] [18]. In short, this is a recognition of the need to act to prevent the institutionalization of practices that can induce increases in energy consumption.

Methodology

This article explores a specific set of data from a broader project – Ecofamilies1 - using only the information related to social practices and the effects resulting from public policies on energy efficiency applied in the lighting area. The data was gathered using two different methods – a survey and interviews – addressing three different groups: families, energy experts and representatives from manufacturers of lighting solutions.

The survey was applied to 142 families involved in the project. Although an effort was made to build a sample that would express the distribution of some relevant social variables in the Portuguese population, in variables like age, education, profession and number of people in the household, the results are significantly different from the ones that can be found among the general population, according to the last Census initiative that was conducted in 2011. Since most families involved did so on a voluntary base, it became more difficult to guarantee the overlap of some social variables. In this sample the most common families are those with children (70%) and single person households are clearly under-represented (in Portugal 21% of households have only one person, whereas in our study not more than 6% of households are in that situation). Regarding age, the youngest and the oldest are under-represented while those between 30 to 44 and 45 to 65 years are on the opposite situation. As for education, those at the first level are under-represented and those with a university degree are clearly over-represented. According to Censos 2011, Portugal has 15% of its population with a university degree whereas in our sample that number is almost half (46,8%).

Taking this context under consideration, when selecting the families to be interviewed there was an effort to guarantee a higher proximity with the national population, something that was not attained only for the education variable. Fourteen interviews were conducted among families and seventeen among experts and manufacturers, although some of the testimonies are not included in this article since they had other areas of expertise in the energy sector (other than lighting).

Lighting practices and energy efficiency

To carry out an analysis of energy consumption in the domestic sector in Portugal it is important to begin by considering its weight in the final energy consumption. According to 2011 data households[2] ranked third among the sectors that assume greater weight in final energy consumption, accounting for 17% of national energy consumption (the first is transport – 37,4% - and the second is industry – 30,1%). Portugal has one of the lowest final energy consumption in the EU27 and the same goes for

1 Ecofamílias (eco-families) had as main goals: to analyze the energy consumption of 225 families spread throughout the country, taking climatic zones under consideration, and proposing alternatives to increase each family's energy efficiency. This project was developed by Quercus – Associação Nacional de Conservação da Natureza, an environmental NGO, promoted by EDP Distribuição, and had the financial support of the Portuguese "Plan for efficient consumption" (PPEC), administered by the Portuguese regulatory commission on energy (ERSE)

2 The values for the household sector do not include the fuel consumption associated with households vehicles (p.13 [21]).

the domestic sector. According to 2010 data, the Portuguese domestic sector uses around half the energy used in EU27 (0,28 toe/per capita vs 0,61 toe/per capita) and below the values used in Spain (0,36 toe/per capita), Greece (0,41 toe/per capita) or Italy (0,52 toe/per capita) (p.32 [20]). This difference in energy consumption across countries is normally associated with a combination of factors such as the different consumption patterns, climate, energy efficiency of buildings, types of heating systems and energy prices [20].

The lighting sector has been one of the most stimulated in order to build more energy efficient domestic lifestyles, given the fact that the implementation of measures, behavioral or technological, is considered to be relatively simple and easy to achieve due to rapid amortization of the initial investment (when needed) and the financial gain for the aggregate that results from reducing energy consumption.

The weight of lighting in the domestic sector in Europe is about 10% (p.73 [17]), whereas in Portugal, recent data indicate a value that is about half the one recorded at the European level. In fact, of the total amount of energy consumed in households, lighting refers only to 5% (p.40-43 [21]).

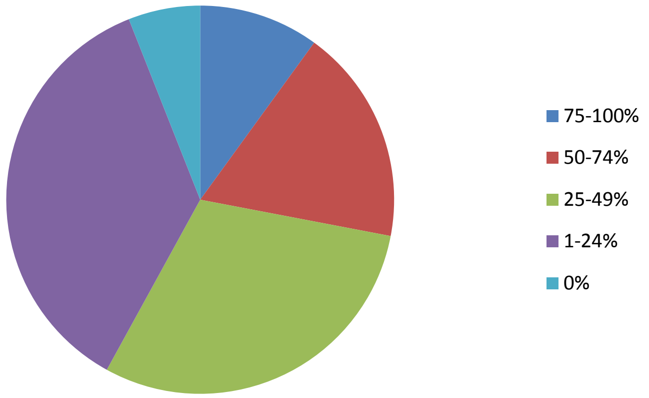
The difference in the proportion of energy used for lighting in Portugal and on average in EU countries can be explained by different lighting needs that result from the availability of daylight hours throughout the year, but also of cultural practices that value the use of artificial light as a building element of comfort [4] [14] [16], a trend that is far more common in northern countries [12].

Although it represents only a small fraction of the total energy consumption in households, national data point to the need to continue to encourage the use of efficient lighting, since there is yet a predominance of the incandescent light bulbs. In fact, approximately 81% of households possess light bulbs of this kind, whereas only 68% have efficient lamps (although tubular fluorescent lamps - those commonly used in kitchens – are used in 80% of Portuguese households). Considering mean values, it is important to note that the number of incandescent light bulbs in use (nine per household) is very close to the number of efficient lamps in use (eight per household).

Another aspect to consider relates to the fact that efficient light bulbs tend to have a higher wattage than inefficient light bulbs. That is, among incandescent light bulbs 40W is the most common wattage, but among efficient light bulbs the most common wattages range from 11 and 14W (the equivalent of 60W or 75W) (p.92 [21]). This situation may result from a rebound effect associated with people choosing a slightly higher wattage when buying efficient light bulbs, since they will still be saving energy and money even though they are acquiring a slightly higher wattage than needed to replace the existent light bulb. But other explanations may be relevant. On the one hand, the replacement of inefficient light bulbs by efficient ones is likely to be directed, primarily, to contexts where lighting use is more frequent and requires higher lighting output, a trend that is corroborated by some studies [22]. On the other hand, due to the need to look for advice in order to identify the best lighting solution for each situation, we may be witnessing an adjustment in the lighting potencies used, assuming that, in some cases, the potency used before was not adjusted to the actual needs.

Among the families involved in the present study we found a very clear perception of the weight lighting has on the energy used in the household, since only 7% of the families refer to it as one of the three most important areas for energy consumption. This perception may be one of the reasons why only 10% of the surveyed families have efficient light bulbs in 75% to 100% of the situations at home. The most common situation is to use efficient light bulbs in between 1 to 49% of the situations (figure 1).

Figure 1. Percentage of efficient lighting in the house



Source: Ecofamilies survey (N – 142)

Regarding the use of efficient lighting solutions and the reasons for their greater or lesser acceptance and use at the household level, there are two aspects to highlight. One is that most of the interviewed families already use efficient lighting at home, although, there are several cases where lack of practical understanding and technical knowledge has hindered a broader use. In any case, public campaigns where CFL were offered had almost no influence among these families. The other is that when asked to identify the main reasons why CFLs are not used more widely at home, the reasons identified by other studies on this matter come up [12] [13]. The main reason identified is the trend to change a light bulb only when it becomes necessary (when the lamp previously used has reached the end of its life). The difficult articulation between efficient light bulbs and existing fixtures and lighting appliances at home, the always present theme of the color of the light, the aesthetical aspect and the response time (how long it takes to achieve full brightness) are also highlighted by families. Costs are seen as having potential impacts in two ways. The more direct impact refers to the need to compare prices when buying a light bulb and the possible tendency to select lighting solutions (for example, improved incandescent bulbs) that are cheaper and, usually, less efficient. The indirect impact may result from the buying of cheaper CFLs whose performance may be disappointing in some of the technical aspects (color of the light – color temperature; lifetime; warm-up times; number of switches) what may prevent future acquisitions. In this context, the fact that some of the interviewees point to the information dimension as one of the most relevant to frame their relationship with lighting technologies is not a surprise. Having difficulties in selecting the best technological solutions for their specific situation is seen as a relevant constraint regarding their agential powers, even when the cost is not a barrier:

> "I bought only one because I didn´t know if it fitted, because I don´t know the lamp sockets. Of the incandescent light bulbs I know. But I wanted to try and bought one and I would like to replace other light bulbs. But then I was disappointed because it didn't fit in the living room lighting appliance I have. (…) I wanted to replace them all and that is way I bought one, but then I didn´t buy any other because I don´t know if they fit."
> Family 4

Despite recognizing the gaps of lighting technologies like CFLs and the difficulties in selecting the best lighting solutions, there seems to be an ability to look beyond them and to consider a wider spectrum of benefits, that include considerations regarding the contribution to society as a all, something that has been highlighted by studies conducted in other contexts [12].

The existence of a broad recognition of the limitations of some of the most efficient lighting solutions stimulated in recent years, allows us to move forward to a central question in this article: the complexity introduced by these new solutions in the decision context of households regarding lighting.

Diversity and complexity

As we have seen, families recognize having difficulties in identifying the best lighting solutions for their needs and even simple features as lamp sockets can be a barrier to acquiring more efficient light bulbs. That can be easily understood if we take under consideration the fact that most families have no technical knowledge about lighting, only practical knowledge that results for everyday practices throughout their lives. Since they now have to integrate different technical features in their choices and uses, some degree of difficulty is easily understandable.

Considering families testimonies and the experts' perspective on complexity and diversity resulting from the changes occurred in recent years in the lighting area, it is possible to identify common trends.

For some of the experts complexity associated with choosing and using light bulbs is understood as a natural reflection of the increasing complexity of modern society and a direct result of the constant technological evolution. For them, information campaigns and the free delivery of CFLs addressed any difficulties that might exist.

But for others, important gaps remain at the time of purchase, installation and use of different lighting solutions with clear disadvantages for families but also for energy policy goals defined at European and at the national level.

The suitability of the most supported technology by public policies (CFLs) to stimulate efficient lighting in different household contexts is challenged by some of the experts interviewed. They claim that in many circumstances CFLs are not the best technical solution and may induce unnecessary energy consumption while eluding families about the energy efficiency of their practices. At the same time, information provided to families on emerging lighting technologies (like LEDs), experts highlight, are not always accurate, since different performing light bulbs coexist and are marketed as equivalent to families that lack the expertise to identify the most relevant features to take into account to distinguish them. This context increases the risk of a bad experience and the possible backlash in the future preventing a wider and faster spread of promising technologies.

But for those experts that recognize complexity and diversity as a potential barrier to families faster and wiser adoption of the best lighting technologies, it's the moment of choice/buying that it is seen as the most relevant. Therefore, empowering families to select the best lighting technologies for the functions they want to see carried out is seen as the most relevant measure that can be taken. Among experts there is a relative consensus on the challenges faced by families in the area of lighting, not only through the generalization of different lighting solutions (CFLs; LEDs; improved incandescent and halogen light bulbs), but also due to the wider number of parameters that have to be taken into account while selecting the most suitable light bulb for each situation.

> "We have many variables that influence lighting, lumens, the return of light, the colder or warmer light, etc... This was not addressed and we considered only the lower consumption. The only technical feature that was addressed by producers was the wattage correspondence in comparison with the incandescent light bulbs. But there are complicated things because some type of lights cannot be replaced by CFL or tubular fluorescent lamps. In the meantime, the improved halogen lamps appeared. And now LEDs are a different kind of light. Until people get used to it…"
> *Interviewee 5 – Researcher in the energy area*

Even at the EU level, the website prepared to "inform consumers, professionals and the media about the wide range of energy efficient lamps currently available, the phase-out of inefficient lamp types and what European legislation is already in place"[3], clearly reflects the increased complexity in comparison to the previous selection criteria that needed to be taken into account when acquiring a new light bulb. In the past, choosing a light bulb implied knowing the desired wattage, the socket and the shape of the light bulb. Nowadays, an informed choice will require paying attention to: light output (lumens), energy efficiency, lifetime, color of the light, number of switches before failure, warm-up time, dimming, operating temperature, lamp dimension and how to dispose of lamps at the end of the lifecycle. Even if some of the technical features do not relate to all the lighting technologies available, knowing what they mean is important if the right choice is to be made according to the different lighting needs in a household.

Therefore, independent advising and information are seen as fundamental strategies to empower families. In a context where families tend to buy light bulbs in supermarkets, and not so much in neighborhood stores where some form of counseling is usually available. Providing standard

[3] http://ec.europa.eu/energy/lumen

information about the different technical features of the different types of light bulbs and even allowing some experimentation by consumers is being recognized as an important step, but mostly regarding LED lamps. Regarding CFLs, the main strategy was to facilitate access to the technologies and not so much empowering families to make informed choices in the future.

Lighting functions

Different studies highlight that changes in the way lighting functions are perceived and defined have a significant influence on consumption associated with this area [15] [16]. A transition from central lighting to o more widespread use of fixtures and lighting appliances (for example, going from a central lamp in the ceiling to lighting a space using decentralized lamps) may lead to an increase in the number of light bulbs per room and the use of lighting beyond functional needs (to include aesthetical, comfort and safety functions) may induce increased energy consumption.

Among the interviewed families there is a clear recognition that the number of lamps and chandeliers that they have today is significantly higher than during their childhood, even if this increase is often framed in a context of efficient lighting integration.

As for the functions associated with lighting it is clear that interviewees feel compelled to contextualize and frame their use of lighting as being the strictly necessary. Even in cases where, in addition to the functional component, lighting is used to provide a safer environment (in cases of detached houses), there is a special care to avoid using energy beyond what interviewees consider necessary.

> “We don’t use lighting to set the mood or to provide an environment, but to show that we're at home. That is, when we go out, there are certain light bulbs which are lit just to show that we are home. When we travel, we leave the clocks that turn lights on and off. But I only use lighting for this.”
> *Family 1*

> “Maybe it is wrong, but one thing I do now and didn´t do before is leaving the outside lights turned on all night. Although we have a dog, the fact is that we have several empty houses around us and there are robberies. So I turn some lights off earlier and others later…but outside I leave them turned on. Not all simultaneously, but either the ones from the top or from the ground floor. One of these sets is turned on.”
> *Family 10*

When it comes to the use of lighting to increase comfort or for aesthetical reasons families tend to assume a very defensive approach and seem to show a sense that such uses are not socially acceptable or can only be triggered in very specific contexts, like when receiving friends or family, contrarily to what happens in other cultural contexts [15] [16]. In most cases where other lighting functions, besides functional and safety, are valued we are dealing with situations that involve moments of social interaction, including receiving guests at home, where the way to light the house or the rooms is seen as an important element the "welcoming".

> “If I get some friends for dinner is obvious that I turn on the lights for the house to become more beautiful. But when they come in I turn some external lights off. There is also the issue of aesthetics. There are lamps that I turn on when I have a dinner, to give a more welcoming environment. In ordinary days it is just what I need. I just create an environment when someone comes”
> *Family 10*

For experts, the broadening of lighting functions is not regarded as a worrying situation, since they believe it is possible to create a comfortable and visually attractive environment in a house using lighting but without a significant increase in energy consumption. Nevertheless, as we have seen before, in some cultural contexts such a change as lead to an increase in energy consumption even if the discussion around efficient lighting was already settled in the public domain.

Discussion

Considering theory of practice and applying it to this study it is possible to identify the role each component plays in defining families’ practices regarding lighting. We start by highlighting the role of **technology or the material structure**. The adjustment recorded since the appearance of efficient lamps, with a clear evolution in the diversity of technologies available on the market, particularly from the moment when less efficient light bulbs were progressively withdrawn from the market, was an important step to consolidate practices of energy efficiency in the lighting sector, but also influenced and encouraged the development of different lighting functions. Difficulties in combining some of the efficient solutions with pre-existent fixtures and lighting appliances and gaps in some of the technical features of technologies like CFLs seem to have played a role as barriers to a wider use of more efficient lighting solutions. Even if in the studied group we have detected a tendency to overcame such difficulties and an ability to look beyond the problems associate with some of the technological solutions, it is reasonable to assume that among the general Portuguese population (that on average is less educated and less mobilized by environmental values than this group) such a trend won´t be as expressive.

In fact, even among the interviewed families, a set of technical features created doubts and worked as obstacles to a wider adoption of CFLs. The lack of **technical and practical knowledge** to identify the best lighting solutions for each case, continue to hamper the process of acquisition and adoption of more efficient lighting solutions, by contributing to a sense of insecurity in terms of investment. Fears about its functionality regarding the existing material infrastructure at home, lack of knowledge of some of the parameters that must be taken into account while selecting light bulbs and even the comfort provided by this type of lighting emerge as important elements. In terms of **meaning / involvement** to the interviewees, comfort provided by lighting, either by their color or by lamps disposition around the house, emerges as an increasingly important factor in structuring practices. It is interesting to note that in terms of lighting functions, comfort and aesthetical components emerge related to restricted contexts, not being admitted as a regular element in lighting practices. Moreover, despite the role lighting plays in constructing a sense of comfort and of well receiving (most of the references to the use of this lighting functionality are framed in the context of receiving guests at home), their adoption tends to be very contextualized in order to avoid falling into the category of wastage.

As for the energy experts, some point to the inadequacy of some of the solutions advocated by public policies in the area of efficient lighting, at least when adopted widely. In this context, the legislative and regulatory framework related to efficient lighting may contribute to their partial failure, mainly due to the stimulus to the generalization of a technology (CFLs) that presents limitations in some situations, particularly in the households' context (CFLs perform better in prolonged use, a situation that is not very common in many household situations). At the same time, the withdrawal of incandescent bulbs emerged as an incentive for the market to come up with new solutions, stimulating a diversification of technical solutions. Such a diversification presents two main consequences. On the one hand, the complexification of choice which could lead to inappropriate and possibly less efficient uses, due to lack of information and training. On the other hand, it opened up possibilities for the development of new lighting functions, broadening the range of parameters that structure the notion of lighting and its link to dimensions that go beyond the functional dimension.

Therefore, this study highlights the different effects that may result from public policies to promote energy efficiency, and that frequently tend to be ignored or disregarded by politicians and energy experts. By disregarding the collateral effects that may result from public policies, we lose the opportunity to understand how they can transform and redefine cultural contexts, concepts, perceptions and social practices and can result in new forms of energy consumption that might counteract the initial objectives of promoting energy efficiency.

Although in the case of lighting some of the interviewed experts consider that the development of new lighting functions does not necessarily imply an increase in energy consumption, because we may be facing contexts of optimal adaptation between technology and functions, when analyzing studies done on this issue we can see that an increase may occur, even if only to occupy the space created by the adoption of more efficient technologies.

Conclusion

In this article we tried to demonstrate the relevance of looking into specific practices in order to better understand energy use. At the same time as we explained how the different components highlighted by theory of practice - technology or material structure; meanings/involvement; practical knowledge; technical knowledge - as the central elements of practices have evolved as a reflection of public policies that aim at improving families energy use, we tried to underline some aspects that point to collateral effects that such policies may have.

In Portugal, certainly due to the geographical location of the country (warm climate and many hours of daylight) and to the prevailing culture who doesn´t value, in the same way as we see in the northern European countries, the use of lighting for aesthetical functions and to build comfort, most lighting uses tend to be restricted to functional aspects. Nevertheless, the changes occurred in countries like the UK and the effects, even if not very evident, some public policies seem to be already having (the difficulties felt by families to identify the best technical solutions, something that can result in wrong choices; or the diversification of alternatives with the inherent diversification of uses) should be read as evidences that if the objective is to reduce energy consumption, than, a different approach must be followed.

Particularly in countries, like Portugal, where lighting practices seem to be framed in a dominant functional approach, a particular attention should be given to the effects of public policies and of the interventions of some stakeholders or professionals that play a relevant role in shaping trends regarding household lighting.

As in almost every situation, prevention is the best option. Therefore, acting in a way to prevent more energy consuming lighting practices to be established appears to be the most reasonable approach to be followed if the objective is to build a more sustainable society.

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Household Energy Saved by Changing Behaviour — a Case Study from Four Islands

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Abstract

Some energy can be saved just by changing behaviour, and this article focuses on advices that can reduce a household's end-use energy. We perform an awareness campaign on four islands (Iceland, Rhodes, Samso, and Tenerife), and the major tools are the following: home energy checks, web-enabled calculators, direct interaction and teaching, as well as collaboration with other islands. We have developed relative saving factors associated with a set of 18 saving advices. Calculations of cumulative cash flows supplement these in order to raise discussions with the households around energy efficiency and also renewable energy. We have found savings in the range 5-20% per household. At least 1/5 of these savings is related to behaviour, that is, they can be implemented at a low cost for the household.

Introduction

There are three general motivations for a household to save energy: (1) Saving energy saves expenditures and taxes, (2) the household saves energy for the next generation, and (3) the household acts locally in the global endeavour to save energy. The European Union aims to increase energy efficiency by 20% by the year 2020, and furthermore, the EU wishes to have a secure supply, to be competitive, and to be sustainable. Home energy savings are thus congruent with the EU policies and regulations for energy efficiency [1][2][3][4][5], and that is an opportunity for energy agencies. There are at least 475 energy agencies in Europe funded by public authorities, and most of them are co-financed by the EU[1]. Four such energy agencies performed the background work for this article based on four islands: Rhodes (Greece), Tenerife (Spain), Samso (Denmark) and Iceland. Each island participates in an awareness campaign that lasts until late 2013.

Generally speaking, the energy flow in a building starts with the fuel input, which is converted by a heating or cooling unit into end-use energy (Figure 1). The figure indicates three major saving advices:

1. Reduce the end-use consumption.

2. Improve the efficiency of fossil fuel conversion.

3. Increase the share of renewable energy in the fuel.

Advice (1) is related to behaviour, and reducing the consumption is usually costless or inexpensive. Advice (2) is related to the building envelope, the efficiency of the energy conversion units, and the

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[1] www.managenergy.net/energyagencies.html

reduction of losses. Advice (3) is related to free energy; it requires an investment to access a source of renewable energy, but the investment can be economically viable.

By a behaviour related saving we understand a reduction in end-use energy consumption (advice 1), which is costless or inexpensive. We focus on behaviour in this work, but we do also include the replacement of equipment and changes to the building envelope, although such changes can be expensive. We include those, because they often appear in our discussions with the households; furthermore, the potential savings are large.

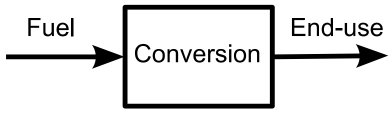

Figure 1. The energy flow determines three major saving advices.

Approach

Our four islands are located in different European geographic areas. Thus we represent four examples of diverse climatic conditions, which allow further islands, and any other geographic area, to extract the measures most suitable for their own context. Knowledge transfer takes place through workshops and pilot actions. Concrete action lines raise awareness among the island households and support the sustainability of the islands.

In total, we performed four workshops of which two were in Iceland. The first workshop, used as a pilot, took place in Grimsey, which is an Icelandic island on the Arctic Circle, north of the main island. The methodology of conducting the workshop, the way households are approached and involved, and the manner in which home energy checks are performed have been tested there. Three pilot action plans have then been set up for Iceland, Rhodes and Tenerife and the established action lines are currently implemented through the respective energy agencies.

A European awareness raising campaign approaches further islands. A workshop in Brussels (April 2013[2]) is the starting point, and at least four other islands are supported in replicating our activities.

We use mainly four tools to invoke the energy awareness of the households [6]. The tools have been selected by an evaluation panel identified in each island and involving local stakeholders that make energy decisions.

- *Home energy checks*. We perform home energy checks by means of a portable computer and spreadsheet software[3] (Excel). The household receives the result immediately in terms of foreseen annual savings of kilowatt-hours and saved costs in euro, or the local currency. Other agencies perform home energy checks using a checklist [7], but in our case, we cannot very well use one standard list of energy saving factors (in kilowatt-hours) in different climates. We have instead developed a set of relative saving factors in order to make the results as relevant as possible to each household (described in a technical annex, Appendix A).
- *Web-enabled calculators*. We have developed simple calculators in several languages[4]. A roof insulation calculator, based on the experience in Grimsey, finds the energy savings when extra roof insulation is added. Simple interactive cash flow diagrams show the economic viability of energy efficiency or renewable energy investments. An electricity price calculator explains and finds the price of electricity (Greece, Iceland). Finally there are four different transport calculators that can help the households make more energy efficient decisions when

[2] brusselsconference.ieepromise.eu/
[3] www.ieepromise.eu
[4] www.ieepromise.eu/en/energy-calculators

buying or driving vehicles. The calculators require no particular knowledge to use, and they provide important information about energy savings in transport, which is the most difficult energy sector.

- *Direct interaction and training*. In Tenerife, households that wish to do so, receive a small training on how to collect the information needed to perform an energy check by themselves. This will mean that apart from the 35 energy checks performed by the energy agency, some more will be performed by *energy ambassadors*, multiplying the results of our activities. In Rhodes, training to children is provided through interactive activities and games that are developed in order to attract children's attention on the topic of energy efficient behaviour. Seminars to teachers enable them to become energy ambassadors.

- *Cooperation with other islands*. Through a European conference, the awareness campaigns implemented in the four islands are disseminated to the public. Existing communication channels, such as the Network of Sustainable Aegean Islands (DAFNI[5]) in Greece, the European Islands Network on Energy and Environment (ISLENET[6]), and the network of islands that have signed the Pact of Islands (ISLEPACT[7]), are used for accessing as many European islands as possible and invite them to reproduce the results and activities.

We would like to uncover whether a household spends little or much energy. A norm would be ideal to have as a reference, but there is no such consensus in the EU. The energy consumption depends, among other things, on the heated floor space of the dwelling, whether it is an apartment or a house, the number of occupants, the climate, and the behaviour of the occupants.

Nevertheless, we reduce everything to a table lookup for all islands. We designed a standard house in a software package (RETScreen) [8], and the software calculates the energy consumption. The software package provides local climate data from satellites or weather stations. The standard house is 138 m^2 of living space — the size was chosen to be medium-sized.

The visited households, however, range from 60 m^2 to 300 m^2. To allow for this variation, we calculate the savings on heating or cooling as relative savings in terms of percentages. For example, given that advice number *i* (*i* in 1, 2, …, 18) saves x_i kilowatt-hours on heating, the relative saving factor is defined as follows:

$$f_i = \frac{x_i}{X} \times 100$$

Here X is the household's total heating consumption. We multiply the relative saving factor f_i by the actual, observed heating demand in the visited house, and that is our estimated savings in kilowatt-hours. In this manner, we mitigate the risk of giving advices that save more than the household actually consumes. Furthermore, the EU goals are themselves given in percentages. The Appendix provides more technical information about the calculations and also the list of basic saving advices that we use.

Assessment of our action

An intermediate and final assessment is being carried out in order to evaluate if the progress of the awareness campaigns is on track compared to the original expectations. The intermediate assessment has been done in April 2013, and the final assessment will be done by November 2013. Indicators that access the advancement of the awareness campaigns are, for example, the number of home energy checks performed in each island (at least 35), to reach energy savings of 450 – 2000 kWh/year per household depending on the island, to reach energy savings of 173,000 kWh/year in all islands together, to reach 1/3 of the island population by media.

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[5] www.dafni.net.gr/en
[6] www.islenet.netwww.islenet.net
[7] www.islepact.eu

Results and discussion

We have found that a cash flow diagram provides a good starting point for discussions at public meetings and home energy checks. Figure 2 shows a cumulative cash flow diagram related to an investment in a solar hot water heater (Calpak, Selective 200GS, 2.84 kW, 4.4 m^2) in Rhodes for a household of three occupants. The diagram immediately provides four pieces of information: (1) the initial investment, in euro, at the end of year zero; (2) the payback period, which is the duration until the balance of the investment account becomes positive; (3) the lifetime of the investment, which is the length of the horizontal axis; and (4) the final profit gained, which is the height of the last bar. The diagram is based on Greek prices and the local climate in Rhodes, or more precisely, the Diagoras airport near Paradisi.

Further background calculations show that the solar fraction is about 75%, which means that a backup, perhaps electric, must step in 25% of the time (RETScreen). We thus view the solar hot water heater as an energy conversion unit that provides 4 times the energy that it consumes, or in technical terms, it has a coefficient of performance COP = 4.

Solar hot water is widely used in Greece, there are several Greek suppliers, and several households are willing to discuss advantages and disadvantages of such an investment. Although the cash flow diagram indicates that it is an economically viable investment, the current financial crisis in Greece prevents many households from making long term investments.

The figure is a screen copy of a web-enabled cash flow calculator that we developed for the households[8]. The household enters basic information, such as the investment cost and the annual savings, upon which the calculator draws a simple cumulative cash flow diagram (disregarding inflation, interest and other, more advanced, financial influences).

Using cash flow diagrams, we have found that replacing an incandescent light bulb with a compact fluorescent lamp (CFL) is paid back in 1-2 years depending on the local electricity prices. The marginal price of electricity varies from 0.08 EUR/kWh (Iceland) to 0.24 EUR/kWh (Samso). The variation reflects the national policies to subsidise islanders. In any case, it is a good investment to buy class A light bulbs, provided that they last as many hours as promised on the package. Changing from incandescent to CFL is no longer regarded as a saving in Denmark, because consumers will change anyway, now that the incandescent lamps have been disqualified by the EU. However, it pays to invest in diode lamps (LED) compared to CFL. The payback period of the incremental investment from CFL to LED is much longer, which we can demonstrate to the households.

Based on 129 home energy checks we have found average energy savings ranging from 1000 kWh (Tenerife) to 8200 kWh (Grimsey) per household [6]. As a rough indicator for Samso, we find savings of 1000 kWh per household related to behaviour, but if we include changes to the building envelope and the heating unit, then we find 4000 kWh per household. The numbers correspond to 5 – 20% savings of the total fuel energy. In Rhodes, the numbers are as follows: 430 kWh of annual savings per household are related to behaviour, and if measures requiring an investment are added, we find at least 2000 kWh annual savings per household. In these two cases, the savings related to behaviour are thus 20 – 25% of the possible savings.

It is difficult to measure the actual savings, since we will not know exactly what the household decides to do, or whether they were going to do it anyway. There are cases, however, where we do know the actual savings. For example, the island of Grimsey decided to follow our advice after our visit, and 24 houses were insulated. Granules of mineral insulation were sprayed into the loft from a truck that was ferried to the island from the main island. Furthermore, 19 houses got new, improved windows. This resulted in 210 000 kWh saved per year. On Samso, a collaboration with a district heating company in 2012 resulted in 13 homes making improvements that they reported on a paper-form signed by the house owner.

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[8] www.ieepromise.eu/en/energy-calculators

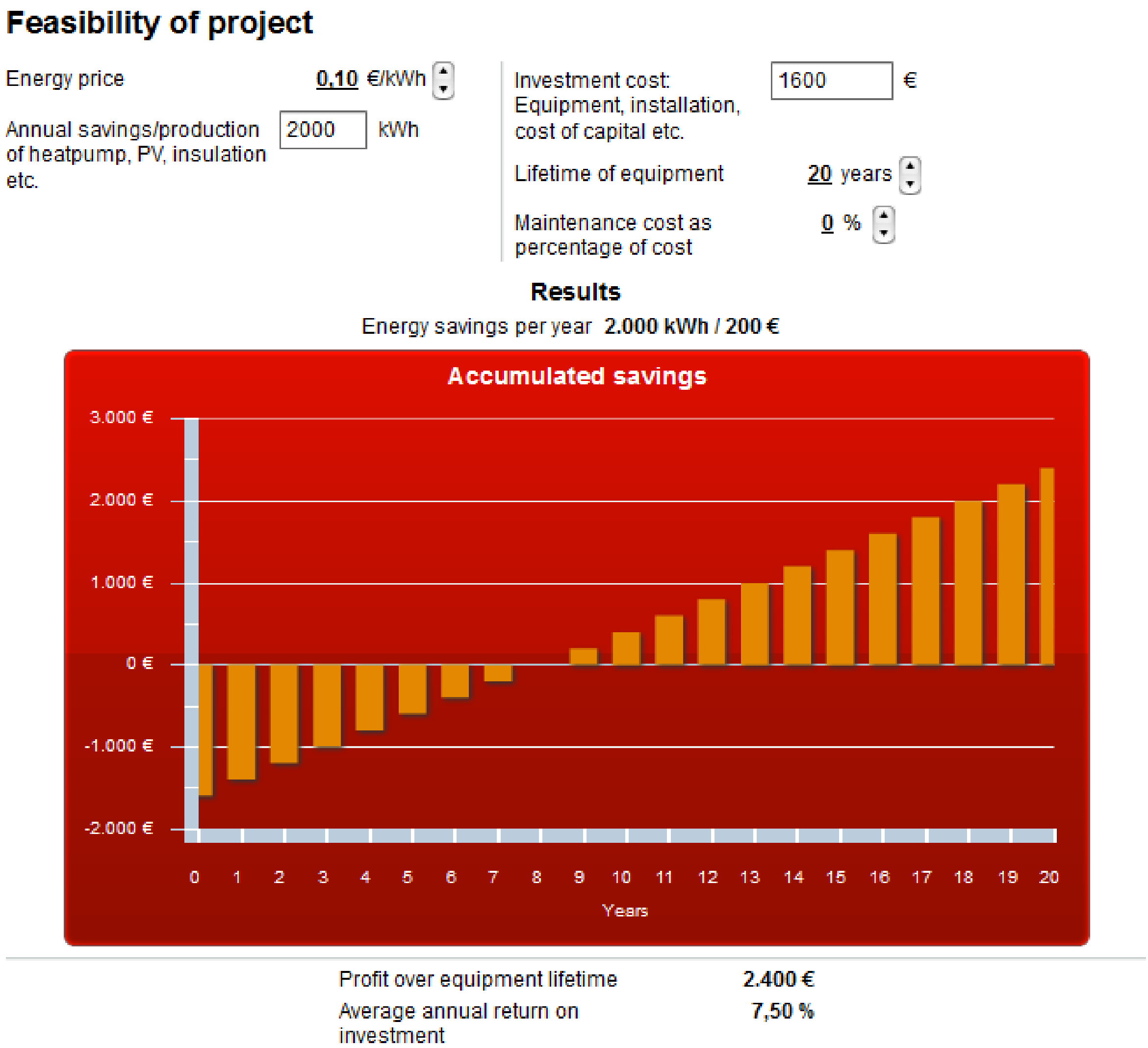

Figure 2. Investment in solar hot water in Rhodes. The diagram shows in one picture: (1) the initial investment, (2) the payback period, (3) the lifetime, and (4) the final profit.

Conclusions

We reckon that at least 1/5 of the possible savings can be achieved by changing behaviour. From a performance viewpoint, building regulations and renewable energy technologies are thus more efficient means to reach the EU goals for the year 2020. However, our work is an awareness campaign, and its objective is to provoke a change in households' energy behaviour. We directly engage in a dialogue with the households, and in this respect the approach is more successful than, say, imposing regulations or penalties by law.

Households are involved through different activities. Firstly, through the workshops in the islands, where we receive the feedback from the households regarding their energy needs both from a technical and political point of view. This activity helped also tailor the awareness campaigns to local needs. Secondly, the home energy checks allow for an even closer and more direct interaction with each household, and they provide tailored solutions for achieving energy savings. These activities have proved to make the citizens become part of the whole activity, and that increases their awareness. We believe that higher awareness increases the willingness to invest in energy efficient technology.

We have used a bottom-up approach, starting with the households and trying to change their behaviour. Multiplier effects are generated through the action lines that are implemented in the islands. In addition, policy makers have been involved in the workshop series and approached during the awareness campaigns. This gives us the possibility to 'intervene' in the political sphere and suggest long-term solutions that support the energy sustainability of the islands.

The impact of our started work will not get lost with the official ending of our initiative. With our work we intend to create the framework for reaching sustainability of started action lines and multiplying their effects even further into the future. Examples are the energy ambassador role of households in Tenerife, or the 'train the trainer' concept followed in Rhodes and addressed to school teachers. Also, the web-based energy efficiency calculators could be integrated into the daily work of the high number of energy agencies distributed throughout Europe.

Acknowledgement

The work is performed within the PROMISE[9] project (IEE/10/312/SI2.589421), which is co-funded by the Intelligent Energy - Europe programme of the European Commission.

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[9] www.ieepromise.eu/en

Appendix A: Technical Annex

The physical relationship between the indoor and the outdoor temperature in a house is simple, in the sense that it is a linear relationship.

Figure 3 illustrates a heated house with indoor temperature T_i, heat loss Q, and an outdoor temperature T_o, which is assumed lower than the indoor temperature for the case of illustration. However, the following is also valid in the case of cooling.

One model is to view the wall as a resistor: The higher the resistance *R*, the less heat flows out of the house. The heat flow is proportional to the temperature difference, as described by the following fundamental law:

$$Q = \frac{T_i - T_o}{R} \qquad \text{(A1)}$$

The corresponding energy is the flow of heat *Q* accumulated over time. Assuming that we measure temperatures at fixed sampling intervals of time t_s, the following is an approximation to the energy loss between two temperature samplings:

$$E = Qt_s = \frac{T_i - T_o}{R} t_s \qquad \text{(A2)}$$

The energy spent for a given period is the sum of all such samples over that period. The indoor temperature is normally rather steady. The outdoor temperature T_o depends on the climate, but it is assumed to be a fixed value during the sampling period, which should be short, for example one hour.

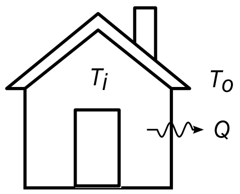


Figure 3. Heat transfer. Definition of variables.

Energy savings

Equation (A2) indicates two ways to save energy: (1) to decrease the difference between the indoor and outdoor temperatures by adjusting the indoor temperature and (2) to increase the resistance *R* by adding more insulation.

In the first case, assume the indoor temperature is adjusted to T_i'. That causes a new heat flow *Q*', and the new energy loss is the following:

$$E' = Q't_s = \frac{T_i' - T_o}{R} t_s$$

The saved energy is the difference $E - E'$ between the original energy loss and the new energy loss. The relative amount of energy saved is then the following ratio:

$$\frac{E-E'}{E}=\frac{\frac{T_i-T_o}{R}t_s-\frac{T_i'-T_o}{R}t_s}{\frac{T_i-T_o}{R}t_s}=1-\frac{T_i'-T_o}{T_i-T_o}$$

By rearranging the equation, we find the energy saved in terms of the original energy consumption:

$$E-E'=\left(1-\frac{T_i'-T_o}{T_i-T_o}\right)E \qquad \text{(A3)}$$

The equation shows that the saved energy is the original energy *E* multiplied by a saving factor

$$f=\left(1-\frac{T_i'-T_o}{T_i-T_o}\right) \qquad \text{(A4)}$$

Since the outdoor temperature T_o depends on the climate, we conclude that the saving factor related to a change of the indoor temperature depends on the climate, through T_o, and not on the degree of insulation.

Example. Assume that the average outdoor temperature during the heating season in Rhodes is T_o = 14° C. According to Equation (A4), the saving factor is the following:

$$f=1-\frac{T_i'-T_o}{T_i-T_o}=\frac{T_i-T_i'}{T_i-T_o}$$

A one degree decrease of the indoor temperature from T_i = 22° C to T_i' = 21° C results in the saving factor $f = (T_i - T_i')/(T_i - T_o)$ = 1/(22–14) = 0.125. In other words, lowering the indoor temperature 1 degree saves the household 12.5% of their energy consumption for heating. If the home is heated by an oil furnace, 12.5% oil is saved. *End of example*.

In the second case, assume instead that the resistance is adjusted from *R* to *R*'. That causes a new heat flow *Q*', and the new energy loss is consequently

$$E'=Q't_s=\frac{T_i-T_o}{R'}t_s$$

By a procedure analogous to the previous one for temperatures, we derive the energy saved, in terms of the original energy, as,

$$E-E'=\left(1-\frac{R}{R'}\right)E \qquad \text{(A5)}$$

The equation has the same form as Equation (A3). In this case, however, the saving factor in parentheses depends only on the insulation, through *R*, and not on the climate.

Example. Assume that the household increases the insulation, such that *R*' = 2.5*R*. Then the saving factor *f* = (1 – *R*/(2.5*R*)) = 0.6. In other words, improving the insulation 2.5 times, results in 60% savings on fuel for heating. If the walls are responsible for a fraction, say, *p* = 50% of the losses of the whole building, then the saving factor corresponding to insulating the walls is *f*(walls) = *f*×*p* = 0.6×50% = 30%. *End of example*.

In summary, only savings related to changing the target indoor temperature depend on the climate.

Hot water is a similar case, because savings owing to a lower target temperature in the hot water tank depends on the climate (through the temperature of the inlet water), whereas savings owing to additional insulation of the hot water tank do not.

Heating value and efficiency

The energy content in a fuel amount *F* depends on its heating value *H*. The energy available for end-use depends on *H* as well as on the efficiency ratio *η* of the heating unit. In combination, the energy available for end-use is the following:

$$E = H\eta F$$

Since the heating value and the efficiency ratio enter the right-hand side as factors, a relative saving (in percent) of end-use energy corresponds to the same relative saving of fuel. The same energy saving factor can thus be applied to both end-use energy and fuel consumption.

For households, it is natural to speak in terms of fuel consumption, but for comparisons, such as energy performance certificates, it is natural to calculate in terms of end-use energy. For us, it is convenient to calculate savings in terms of relative energy saving factors, because we avoid having to consider heating values and efficiency ratios in the saving advices.

Saving advices

Table 1 shows the relative saving factors related to the four islands. Each saving factor is to be multiplied by the fuel consumption observed by the household. Furthermore, the result must be multiplied by the number of saving items found.

For example, if a household agrees to lower the indoor temperature by two degrees, rather than one, the first advice must be multiplied by a factor of two. Similarly, if the household agrees to lower the temperature by 1 degree during the night only, for 8 hours rather than 24 hours, the advice must be multiplied by 8/24.

Table 2 shows the advices related to electricity. These are not percentages, because the electricity consumption of the electric appliances, such as light bulbs, is assumed independent of climate; the numbers are thus absolute savings in kilowatt-hours (kWh).

Table 1. Relative saving factors [%] related to heating and cooling advices.

Advice	Grimsey	Rhodes	Samso	Tenerife
Lower indoor temperature 1 degree C always	5	13	8	13
Same for cooling	—	17	—	31
Upgrade to energy windows	12	12	12	12
Same for cooling	—	12	—	12
Improve the wall insulation 2.5 times	30	30	30	30
Same for cooling	—	30	—	30
Improve the loft insulation 2.5 times	18	18	18	18
Same for cooling	—	18	—	18
Seal air leaks around doors and windows	5	13	8	13
Same for cooling	—	17	—	31
Improve heating unit: lower thermostat, lower pump speed, insulate boiler, service checks, renew burner	1	1	1	1
Lower the temperature in the hot water tank one degree	1	2	2	2
Save a litre of water per person every day	2	2	2	2
Install a solar hot water heater [8]	33	73	49	78

Table 2. Absolute savings [kWh] related to electricity saving advices.

Advice	Grimsey	Rhodes	Samso	Tenerife
Avoid standby mode	40	40	40	40
Raise temperature in refrigerator or freezer 1 degree	22	22	22	22
Lower temperature in a washing device (dishwasher from 60 to 30 C, washer from 90 to 60 or from 60 to 30 C) [1] [2]	152	152	152	152
Upgrade a washing device from class C to A++ [1] [2]	110	110	110	110
Upgrade a tumble dryer from class C to A++ [4]	311	311	311	311
Replace an old light bulb by a CFL [3]	45	45	45	45
Replace an old refrigerating device from class C to A++ [5]	414	414	414	414
Replace an old circulation pump by a class A pump[10]	280	280	280	280
Install PV panels[11], per m^2	103	206	142	242

[10] svk.teknologisk.dk

[11] re.jrc.ec.europa.eu/pvgis/

Residential Energy Consumption Habits: The way European Consumers use energy and their perceptions regarding Energy Efficiency

Silviya Yordanova and Mihai Petcu

CODA Strategies

Abstract

The new realities of implementing the 20-20-20 objectives have seen the main players of the electricity supply value chain turn more and more to consumers, be it through energy efficiency programs or more recently through dynamic tariffs and demand response initiatives. Research into the consumption habits of households and their views on energy efficiency are scarce, or are usually carried out on a country by country basis. As part of a wide multi-client study on residential energy consumption habits, CODA Strategies has carried out a study of just over 3,000 telephone enquiries, with consumers in France, Germany, Italy, Spain and the UK.

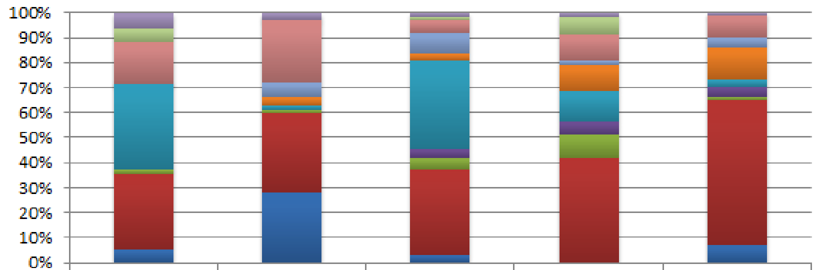
The study pointed out that a majority of the households in the surveyed countries do not own energy efficient heating, cooling and lighting systems. Investing in better control infrastructure, either for improving energy efficiency or for increasing comfort are not a priority in the current economic context.

Consumption practices

Through our survey we were able to determine the residential heating and lighting equipment parks in 5 large European countries.

Heating and cooling equipment in European households

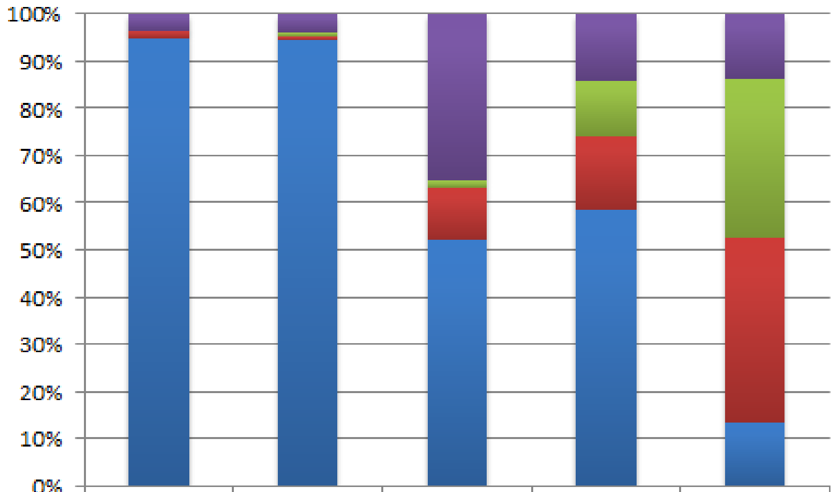
Heating equipment differs in the European countries but conventional electric heating (radiators and convection heating) and gas boilers present a strong penetration in most of these countries.



	France	UK	Spain	Germany	Italy
Other	7%	3%	2%	2%	1%
Urban heating - heating network	5%	0%	2%	7%	0%
Central heating- collective gas boiler	17%	25%	5%	11%	9%
Central heating - collective oil boiler	0%	6%	8%	2%	4%
Heating pump	0%	3%	3%	11%	13%
Electric heater	34%	2%	35%	12%	3%
Central heating - propane individual boiler	0%	0%	3%	5%	4%
Central heating - wood boiler	2%	1%	5%	9%	1%
Central heating- individual gas boiler	31%	32%	34%	42%	58%
Central heating - individual oil boiler	5%	28%	3%	0%	7%

Graph1: Heating equipment in the households Question: "What is heating system in your household?"

Collective heating is more common in countries with long and cold winters. In Spain and Italy the part of collective heating is 15% and 13% respectively, compared to France and the United Kingdom where the part is 22% to 30% respectively. The share of individual gas boiler use remains strong in all countries with at least 1/3 of households employing this source of heating. In Italy the share is even stronger, 58% of households being heated with gas boilers. Heat pumps are still a small market in most European countries, except for Germany and Italy where 11% and 13% of households respectively use this technology. Heat pumps in Germany are mostly used for heating and hot water only (non-reversible). In 2011, 65 873 systems were installed with 57020 of them used for heating. In Italy the heat pumps are usually reversible; they are thus used for both heating and cooling. 99% of all heat pumps installed in 2011, were reversible.



	France	UK	Spain	Germany	Italy
An integrated air conditioning	3%	4%	35%	14%	14%
Several mobile air conditioners	0%	1%	2%	12%	34%
One mobile air conditioner	2%	1%	11%	16%	39%
No system	95%	94%	52%	59%	14%

Graph2: Households equipped with air-conditioning units Question: "Do you have an air-conditioning system?"

There is obviously a higher penetration of households equipped with air-conditioning systems in the Southern countries. In France and the United Kingdom, 95% of households do not use such systems; In Germany only 41% of households use cooling systems. Spain sees only 48% of households owning a cooling system. Previous CODA Strategies studies show an annual growth of the market over the last 12 years. In 2000, only 16% of Spanish households were equipped with such a system. Italy remains the country with the strongest penetration of air-conditioning in the residential sector; 86% of homes have an air-conditioning unit.

The share of mobile air conditioners is stronger than that of integrated systems. They are preferred mostly due to price consideration and apparent ease of use.

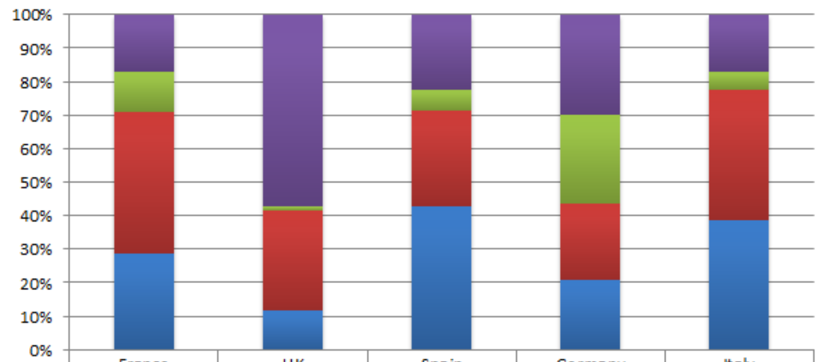
Regulation systems

Heating system regulation is obviously easier in the case of individual heating systems rather than of collective ones. The share of collective heating in the surveyed countries is not particularly high.

The CODA Strategies survey aimed to identify the most common heating regulation equipment in the residential sectors of the selected European countries, be it simple thermostats, programmable thermostats or more complex thermal regulation systems.

The graph below points out that households equipped with a more complex climate-based regulation system are mostly found in France and Germany. These two countries are considered the biggest markets in the area of thermal regulations and home automation systems in Europe.

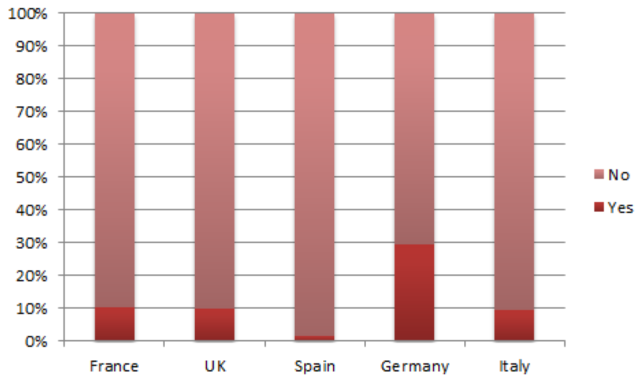
Programmable thermostats that can turn on/off the heating at a given time are used by almost 1/3 of households.



	France	UK	Spain	Germany	Italy
No system	17%	57%	22%	30%	17%
A regulator that regulate the heating system	12%	1%	6%	26%	5%
A programmable thermostat	42%	30%	29%	23%	39%
A simple system to indicate the temperature	29%	12%	43%	21%	39%

Graph3: Thermal regulation systems in European households. Question: “What kind of regulation system do you have?”

The share of systems permitting remote regulation appears as considerably weak in most European countries, the only major exception being Germany, which sees uptake rates averaging 30%.



Most of the thermal regulation systems are going with services such as control of the heating, air-conditioning, lighting and others at distance. Clients have the possibility to control their usages through their computer or mobile phone.

The part of households owning those devices is not very high in the European countries except Germany where 30% of the families have this kind of systems.

Graph4: Use of remote regulation systems throughout Europe. Question: “Do you use regulation remote control heating?”

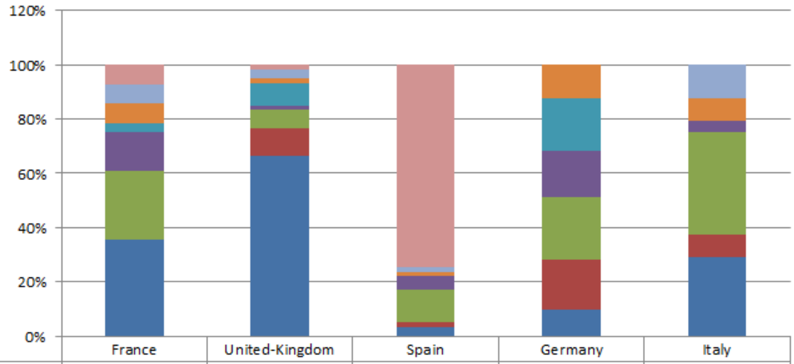
The above graph shows that remote regulation system use is scarce throughout the household park of the 5 countries covered by our survey. Only 10% of households in the United Kingdom, Italy and France and even less in Spain use such a system. This type of equipment is still perceived as unnecessary luxury and households with moderate incomes tend to avoid such systems.

Lighting equipment

Lighting consumption amounts to about 10% of the energy consumption of European households. An important factor in the reduction of electricity consumption is the penetration of LED technology as well as the increasing performance of lighting systems and their use by the occupants.

Through its survey CODA Strategies sought to determine household equipment rates of lighting control and lighting efficiency systems. The results show countries at a different level of development in terms of lighting control use. Spain shows the highest percentage of households with no energy efficiency improvements of their lighting systems - 73% of all households have made no investments whatsoever. On the other hand, presence detectors for exterior lamps and detectors for places not permanently occupied are wide-spread solutions in UK, Italy and France.

Lighting control systems are still a small market in the 5 European countries surveyed. The most developed of these markets remains Germany with 12% of households possessing a lighting control system.



	France	United-Kingdom	Spain	Germany	Italy
No system	7%	2%	75%	0%	0%
Other	7%	3%	2%	0%	13%
Lighting management system	7%	2%	2%	12%	8%
Radio remote controls	4%	8%	0%	20%	0%
Lighting power variable for chandeliers, lamps etc.	14%	2%	5%	17%	4%
Lighting power variable for the lampposts	25%	7%	12%	23%	38%
Presence detector in parts not permanently occupied	0%	10%	2%	18%	8%
Presence detector for exterior lamp	36%	67%	3%	10%	29%

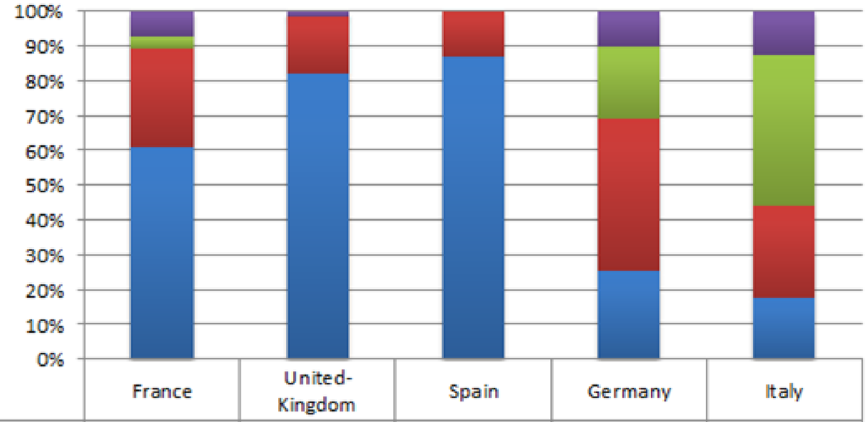
Graph5: Households having lighting equipment, Question: " Which of the following equipments do you have?"

The consumer supplier relationship

One of the multiple expected effects of deregulation of the European electricity markets was more choice for the end-customer, in terms of the electricity supply. Retailer competition was expected to fuel this dynamic, lowering prices and providing better adapted tariff options. This implied that consumers would be looking to optimize their subscriptions and modify their consumption according to the different tariffs selected.

The use of "time-based" tariffs

The use of electricity time-based tariffs in Europe, which is particularly important in some of the countries covered by CODA Strategies' quantitative enquiry, is usually the consequence of historical programs (at times launched by the local monopoly before deregulation). For example, in France, time-of-use tariffs, with a day-night (high consumption – low consumption) price shift, have been in force since the late 70's.



	France	United-Kingdom	Spain	Germany	Italy
Other	7%	1%	0%	10%	13%
Dynamic tariff with several time differentiated tariffs	4%	0%	0%	20%	43%
Dynamic tariff day/night	28%	16%	13%	44%	26%
Flat demand tariff	61%	82%	87%	25%	18%

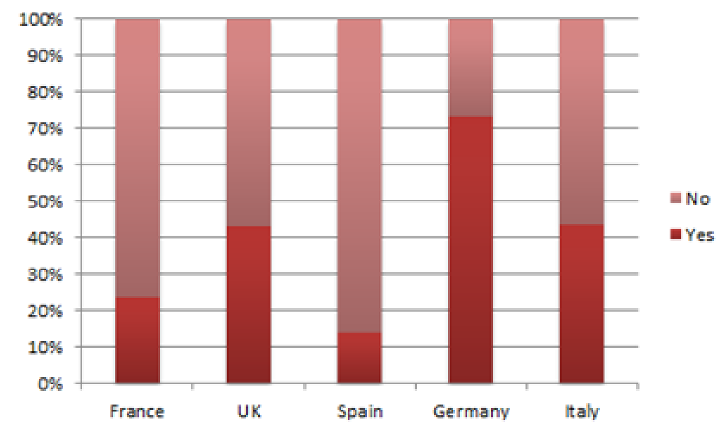
Graph6: Type of tariffs used by end-customers, for each country, Question: "What type of electricity tariff do you have?"

As the above graph shows, dynamic tariffs are in use in all of the 5 countries surveyed. Their use is particularly strong in Italy, where only 18% of interviewed consumers, were still using a flat tariff. The country showing the lowest rate of time-based pricing penetration is Spain, where historically the major utilities have not been involved with this type of programs. The United Kingdom also sees little dynamic tariff use, despite its considerable competition and the ease of associated to switching both rate schemes and suppliers in the UK. The country still uses pay-as-you go programs (which are considered flat-tariffs for the study as there seems to be no correlation between this type of pricing and a drive for energy efficiency), yet it sees essentially mostly flat tariff use. Only 16% of the British consumers interviewed for this study use a dynamic tariff, mainly a day/night tariff.

41% of the French consumers interviewed by CODA declare having subscribed to a dynamic tariff. About 28% of these consumers use a day/night ("Heures pleines / heures creuses") tariff, which is associated to an electric water heater (and a relay for controlling this water heater according to the tariff periods). 11% of consumers declare using other types of tariffs (with only 4% using the more complex Tempo tariff).

Germany and Italy both see high penetrations of price based schemes. Germans use mostly "2 period" day-night tariffs, while the Italians use more complex schemes with several price levels. 43% of Italian consumers interviewed for the study adhere to these more complex tariffs.

Consumers who use flat tariffs seem to do so, at least in part, due to a lack of knowledge of their alternatives. As the graph below shows, of the consumers that declared using such tariffs, only the German and to a certain extent, the Italian and British respondents are aware of the existence of dynamic tariffs.



Only 20% of French consumers using a flat tariff are aware that other tariff options exist. Yet the lowest share is in Spain, which incidentally also shows the lowest penetration of time-based pricing.

Italy, the UK and especially Germany see more informed consumers, these consumers choosing to stay on a flat tariff, while being aware of their alternatives.

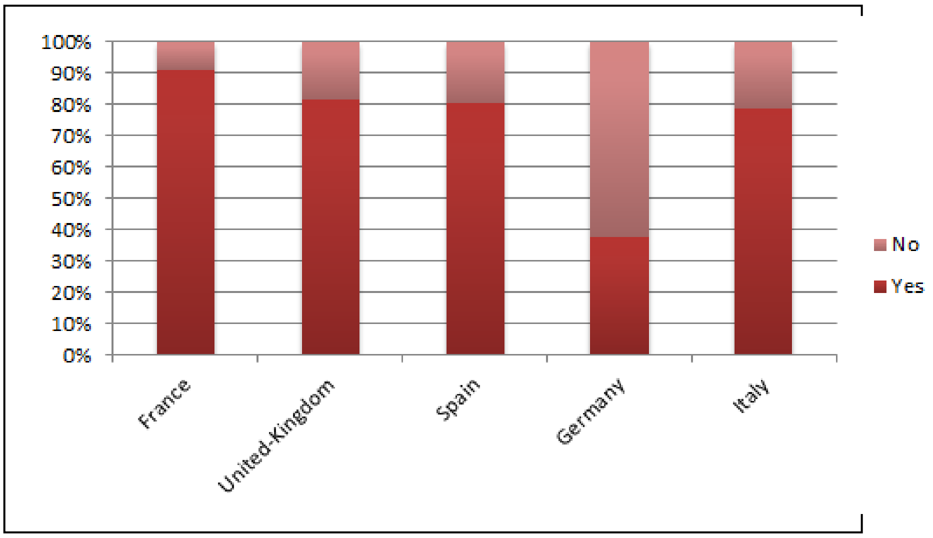
Graph7: Knowledge of customers using flat tariffs of their alternatives, **Question:" Do you know other electricity tariff?"**

The fact that close to 70% of German respondents and just over 40% of Italian and British consumers are knowledgeable of dynamic tariffs, yet choose to stay on a flat tariff, would indicate that these consumers consider these tariffs uninteresting from an economical point of view or requiring too much effort for what would be insufficient gains.

The levels of satisfaction with current suppliers and the interest in switching

The CODA Strategies survey identifies a generally positive relationship between consumers and their suppliers. For all energies with the exception of electricity and in some countries, for gas, most consumers are not aware of their alternatives (despite aggressive marketing campaigns from alternative suppliers in some of the countries that were surveyed).

In the case of electricity consumers are more knowledgeable of the euxistence of different suppliers, other than their own. In general however, most consumers appear pleased with their existing supplier. As the graph below shows, France and the UK showed significant levels of customer satisfaction, whereas Germany showed significantly less, fewer than 40% of consumers being happy with their current supplier.



Graph8: Satisfaction with current electricity supplier. Question: "Are you satisfied with your current supplier?"

Most Germans declaring themselves unsatisfied with their current supplier cited a lack of tariff options (and a poor adaptation of these tariffs to their consumption needs). The lack of “green energy” (from renewable sources) in the retailer’s energy mix was also cited by about 20% of interviewees. The price competitiveness of the current supplier, compared to other suppliers, was not deemed a major issue of dissatisfaction.

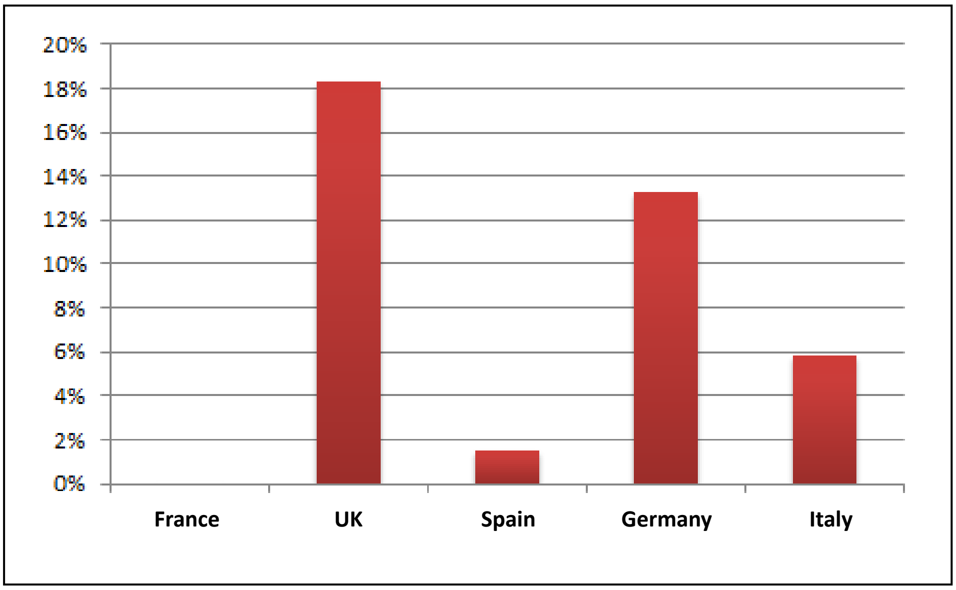
While in France, where residential electricity prices are low, consumers not being dissatisfied with their supplier from a price performance point of view is understandable (4% of consumers nonetheless quoted high prices as their main point of dissatisfaction), this is not the case in the UK, in Italy, or in Germany, where prices are considerably higher. Although in Italy almost all unsatisfied respondents claim “electricity prices” as their main argument for dissatisfaction, they only stand for about 20% of all Italian interviewees, the rest being quite satisfied with their current supplier and not looking to switch.

In the UK, most interviewees also declare being satisfied with their consumer, fewer than 5% arguing either that prices are too high (which is arguably enough to motivate a switch), or that other suppliers may provide more assistance and technology (in-house displays, for example).

In Spain, the price of electricity is the main point of dissatisfaction for nearly all of the respondents declaring themselves unsatisfied with their current supplier.

In the case of gas, the only significant figures come from the UK, where close to 13% of consumers are unsatisfied with their current supplier, the single reason cited being high prices. Consumer dissatisfaction rates seem lower in the other countries, with Germany coming in at a distance second with about 7% of consumers being dissatisfied with their gas provider, with 6% considering switching as a result.

Consumer switching for electricity appears generally low. Throughout the 5 countries that were surveyed, only the UK and Germany show some consumer interest in switching electricity supplier – with 18% of British consumers and about 14% of German consumers declaring “having considered switching electricity” suppliers. French and Spanish consumers do not consider changing suppliers (0% and 2% respectively) and only about 6% of Italian consumers consider doing so, with price being the major driver for switching.



Graph9: Consumer switching rates in the different countries. Percentage of consumers having answered “Yes” to the question: “Have you considered switching suppliers during the last year?”

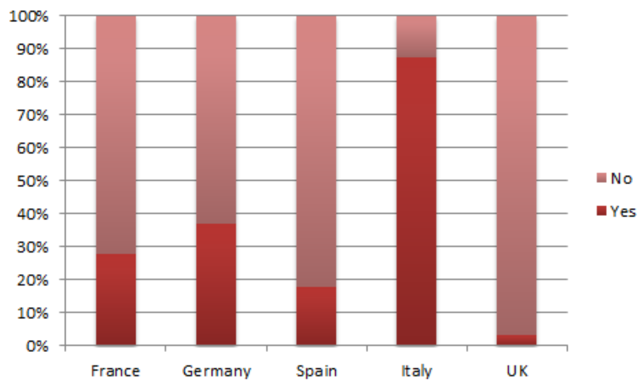
Consumer intentions to invest in energy efficiency systems

Energy efficiency systems are not largely developed in the European household park for a number of reasons such as the high price, the difficulties to install, lack of information from professionals etc.

Through the survey, CODA Strategies identified the main reasons for investment in energy efficiency systems and the short term investment plans of the interviewees.

Intentions to reduce energy bill

The reduction of the energy bill passes firstly by the household intentions to reduce them and the daily efforts toward this objective.

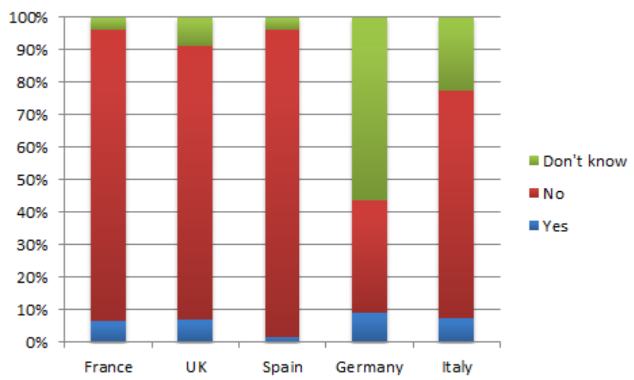


The will of the households to reduce their energy bill by delaying their usages at a time when the energy is less expensive differs from one country to another. Opinions differ significantly between Italy and UK where 88% of the Italians declare to be ready to modify their usages against 3% of the British. In France, Germany and Spain the households are also reluctant about this with only 29% to 39% ready to do it.

Graph10: Households that answered the question "Could you consider to delay your usages according to the price of the energy?"

Intentions to invest in heating and lighting systems

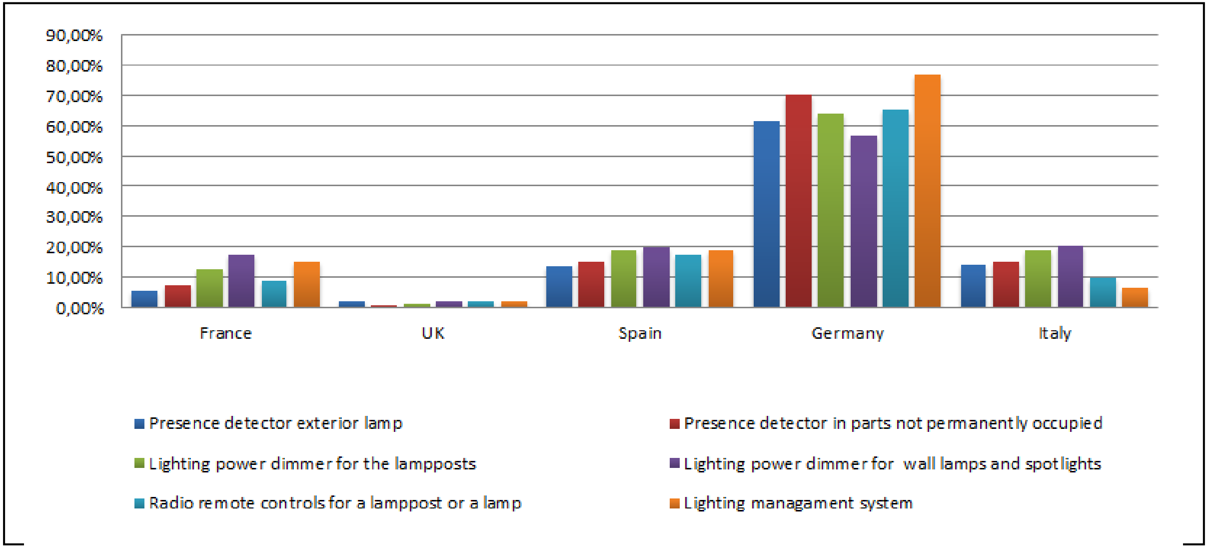
Investment in the residential market for energy efficiency solutions have dropped significantly in the last 4 years, especially in Spain and Italy (previous CODA Strategies survey carried out in 2009, saw considerably higher rates on investment in all countries and across all equipment families). In the current market context, households are not willing to invest in new heating, air-conditioning or lighting control systems for energy efficiency.



Due to the difficult economy situation in Europe, households are reluctant to invest in renovation projects. Even in the countries less affected by the crisis, the uncertainty persists and the households prefer to wait for the economy to recover. 10% of the German households declare to have projects to change their heating systems against 55% that are not decided.
In France, UK and Italy 7% will renew their heating systems and only 2% in Spain.

Graph11: Propensity to invest in more efficient heating systems, throughout the 5 countries. Question: " Are you considering refurbishing your heating system in the following 5 years"

The CODA Strategies survey also focused on determining the investment priorities, in terms of energy efficiency projects, according to the different system classes.



Graph12: Purchase of one of the following systems in the next years, Question:" Are you considering investing in one of the following systems in the next 5 years"

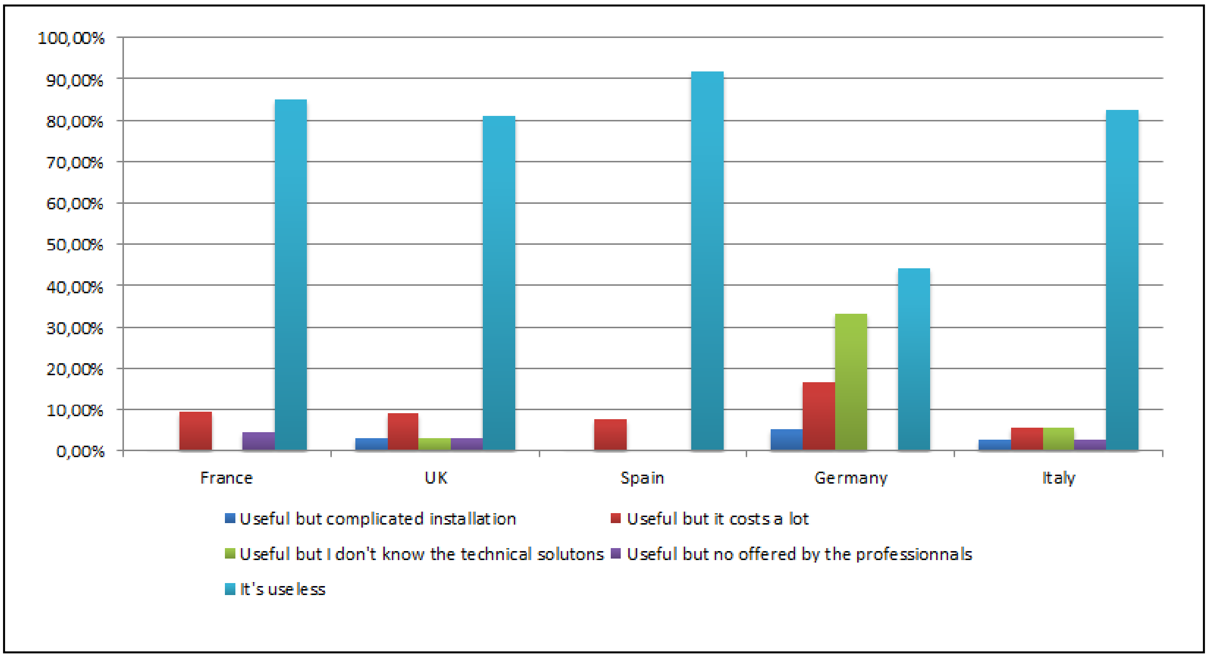
Only 20% of the households in France, Spain and Italy are planning to invest in rendering their current lighting systems, more energy efficient. The UK shows by far the lowest propensity to invest in lighting system refurbishments. Fewer than 5% of British interviews declared any willingness to improve their current configurations. German interviewees, on the other hand, show a considerably stronger propensity to invest in lighting control upgrades, within the following 5 years. More than 60% of Germans will carry out such a project.

In terms of systems, the French, Spanish and Italians will most likely upgrade their current configurations with the addition of dimmers, this type of project being announced by roughly 20% of interviewees. Full lighting control systems come in at a close second in France and Spain.

In Germany, the preference seems to be for a full system refurbishment and for the integration of a full lighting control system, complete with dimmers, remote controls and presence detectors. The results clearly show that German consumers are expecting to obtain a higher level of energy savings from upgrading their systems, than consumers from the other countries.

Investment barriers

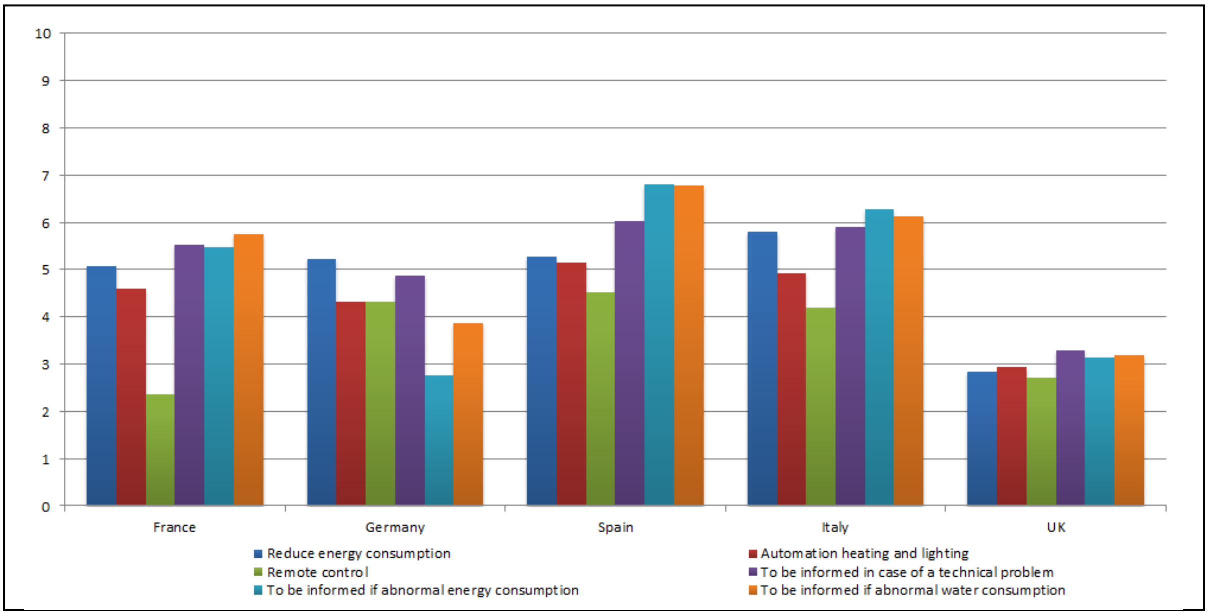
The CODA Strategies survey also considered the main reasons why households in the selected European countries chose not to invest in more efficient lighting systems.



Graph13: Reason not to invest in a lighting solution, Question: "What are your barriers in investing in lighting project?"

More than 80% of households in France, UK, Italy and Spain find it useless to invest in lighting systems, as they consider the expected gains in terms of energy efficiency as insufficient, especially when taking into account the costs of the equipment / systems. In Germany only 44% of interviewees see the investment as pointless. In France, UK and Italy a roughly 5% share of the study population expressed interest in investing in a more energy efficient lighting system, whilst also indicating not getting sufficient information on the subject from their traditional home automations provider or from different installers.

Price is also a barrier for investment in these solutions. The period of return on investment is considered as being too long, particularly among customers with small monthly bills.A good deal of consumers also considers control and regulation systems, both for lighting and for heating, as being of insufficient value, arguing that they are not required and that both heating and lighting can be run in an efficient manner, without the use of such systems.



Graph14: Note from 0 (no interest) to 10 (essential) of the following services that could be proposed

As the above graph shows, in all countries apart from Germany, reducing energy consumption is not one of the central issues concerning households. Unsurprisingly, mainly due to high energy prices, any application being commercialized on a proposition of “reducing consumption” seems to be considered of some value (5 out of 10).

Applications that simply inform, but do not act independently also seem to gather significant interest from the interviewees. Monitoring of abnormal consumptions from a multi-fluid perspective (energy, gas, water) is of high importance in most countries, but particularly so in Spain, where monitoring systems are graded at close to7 out of a possible maximum of 10 as per the value they bring to the consumer.

British interviewees seem to see both monitoring and control systems as being of particularly low value, where as Spanish and Italian cosumers consider these applications significantly more valuable.

Remote control of household systems, either for energy efficiency or for comfort seems to be considered as the application with the lowest value, by the interviewees in all countries.

Conclusion

The results of the CODA Strategies survey points out that the equipment parks in the 5 European countries that were studied are essentially inefficient from an energy consumption point of view. More so, the use consumers make of the equipment is also not oriented towards optimizing energy consumption or energy use. The study does seem to highlight the important potential that can be tapped into by a host of actors, through fairly simple measures such as providing better information to consumers and creating new incentives such as more dynamic tariffs and combining them with technology. The study also identifies the differences between consumers in the 5 countries: the French and especially the Germans seem more likely to invest in energy efficient equipment, while Italians and to some extent the Spanish are willing to change behavior to improve their consumption. This all shows that while one type of incentive will not be adapted to every country, developing programs for increasing energy efficiency related investment and practices can have an important impact on the contribution that consumers may make to balancing the European grids, in the context of the 20-20-20 objectives.

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Influence of user behavior and home automation on energy consumption

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Abstract

This paper discusses how consumer behavior influences energy consumption in buildings. The basis for this is measurements of temperature, humidity and CO_2 concentration which were carried out in more than 80 apartments over a two week period between November 2012 and March 2013 with a high temporal resolution. We analyzed the energy consumption in apartments with a separate energy meter. The data was corrected for climate variations and by using heating degree days the yearly energy consumption was estimated. As a result we found significant differences in energy consumption in comparable buildings concerning their structural and physical characteristics. These differences cannot be explained by the different room temperatures although the room temperatures varied a great deal between the apartments. Our results show that the reasons for these differences are different ventilation strategies. In apartments with low energy consumption the ventilation period was only a few minutes whereas in apartments with high energy consumption the windows were open for several hours. The different ventilation strategies are habits of the household members so that they were constant over the measurement period. Automatic temperature regulation with timed control of temperature is considered as one important task of home automation[1], which is correlated to energy consumption. A number of sample households have time controlled temperature regulation of different rooms. In these apartments the room temperature varied more over a period of a day than in an apartment without automatic temperature control. In addition, the average temperature of apartments with automation was lower than the average of the whole sample. Interestingly, households with an automatic temperature control system were ventilated done for short periods of time more frequently. Due to these two facts the energy consumption of households with automatic temperature control is considerably lower than the average energy consumption of the sample. We expected lower energy consumption during the night but discovered that this is not the case in many households. Samples show that this is because of the settings of the circulation pump or the heating system characteristics. Almost every heating system had a programmable timer, but the measured temperatures in the night did not show expected temperature level reduction. Therefore the setting of the heating systems should be checked and adjusted.

Introduction

The city of Bottrop, where the University of Applied Sciences Ruhr West is located, participated successfully in the competition for Innovation City Ruhr [6]. The competition's aim was to find an exemplary region that showed how energy consumption in the region can be reduced by 50% by 2020. In addition to reduction of energy consumption in industry, trading and the service sector, Innovation City Ruhr is also focusing on the residential sector. It is important for the house owners to choose a proper strategy to improve energy efficiency. Several studies have shown that energy performance does not only depend on building properties (e.g. insulation), but also on user behavior [1], [2]. "It is found that the most important (sensitive) parameters are related to occupants' behavior." "This point will be even more important when the permitted energy consumption is further reduced in future due to the fact that a relatively higher proportion of the consumed energy is related to user behavior including hot water consumption." [4]

For that reason house owners were consulted about improving the energy efficiency of their buildings by the Innovation City Management GmbH in Bottrop. For this consultancy several data like energy consumption, year of construction and surface area were recorded. Based on this data the specific

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[1] Home automation is the residential extension of building automation. It is the automation of the home, housework or household activity. Home automation may include centralized control of lighting, HVAC (heating, ventilation and air conditioning), appliances, security locks of gates and doors and other systems, to provide improved convenience, comfort, energy efficiency and security [7].

energy consumption in kWh/m^2 was calculated. The energy consumption varied widely between buildings with different years of construction but which are comparable to their structural-physical characteristics. Figure 1 shows the calculated yearly energy consumption per square meter for different types of buildings and heating systems based on the data of energy bills.

Despite a huge spread in the data, a dependency of energy consumption on the year of construction can be observed for natural gas powered one-family houses. This trend is not valid for multi-family houses. Taking all buildings into account it seems that the age of the building and its structural properties have only a small effect on the energy consumption.

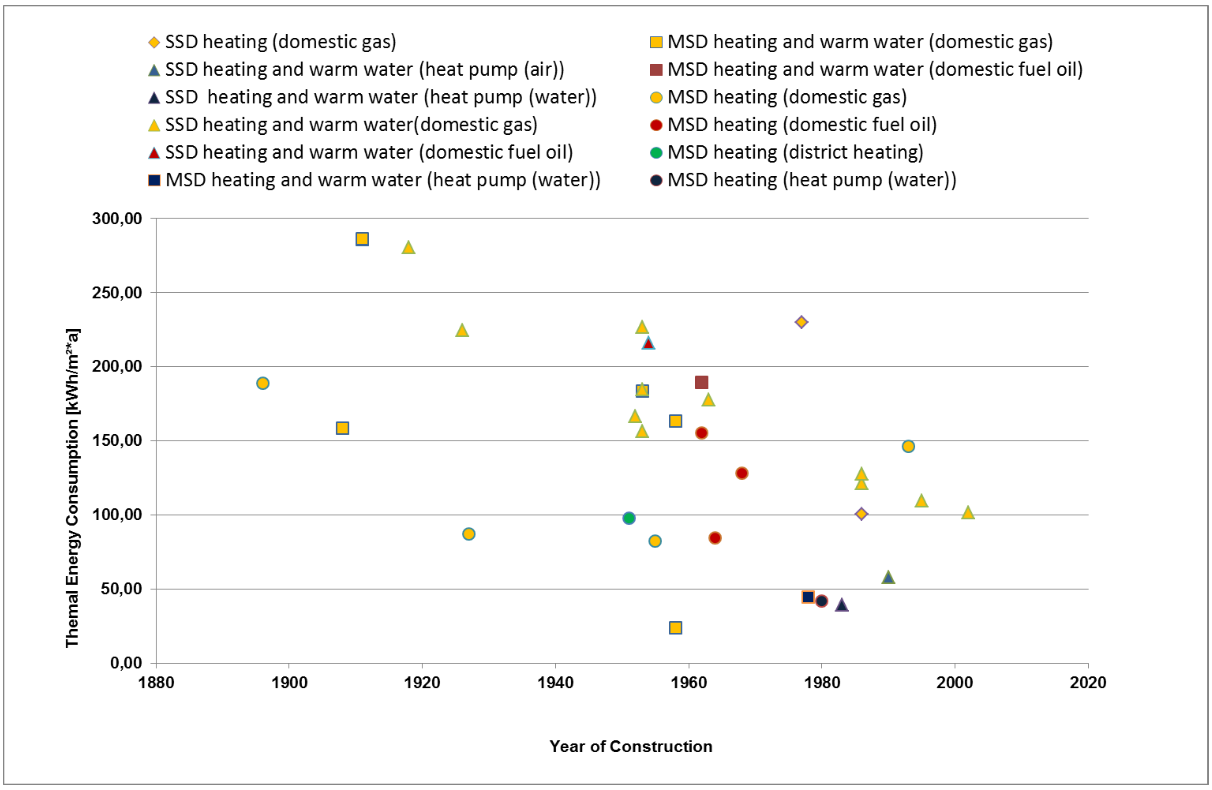

Figure 1: Specific energy consumption depending on the age of the building according to the energy bills (SSD=single-storey dwelling, MSD=multiple-storey dwelling)

To understand this effect we worked with 800 households that had agreed to participate in the energy consultation. We asked if they were willing to participate in measurements of their indoor air quality for at least one week. We received more than 100 positive answers, so that measurements were carried out in 80 households between November 2012 and March 2013. Motivation of participants was not only based on prospect of energy and costs savings but also of increasing comfort (see also [5]). We asked the participants not to change their normal behavior of ventilation and heating during our measurements. The apartments were equipped with mobile data loggers in different rooms for one to two weeks. Indoor air temperature, relative humidity and CO_2 concentration were recorded with a temporal resolution of 3 minutes. After collecting the loggers the data was transmitted to a SQL data base.

First evaluation of results

For analyzing the data a day was divided into four periods:

1. Morning - from 6:00 am to 8:59 am
2. Day - from 9:00 am to 5:59 pm
3. Evening - from 6:00 pm to 23:59 pm
4. Night - from 0:00 am to 5:59 am

These periods were chosen to characterize typical presence at home. For the time periods the average values were calculated. Figure 2 shows the average CO_2 concentration for the different periods in a day in the living room of the different apartments of the sample[2]. The CO_2 concentration is a good indicator for presence of people in a room, which can be seen in Figure 2. In all households we found periods were the living room is not used. The indication for this is the same CO_2 concentration in the room as that of the outside air in those periods. Figure 2 also shows the average air temperatures of the living room in the different households of the sample. The average temperature of the living room differs considerably (from 18 °C to 25 °C) between the different apartments. Although the living room is only used during some periods of the day, the temperature in the room is almost constant during the whole day in 75% of the households of the sample. In particular, the high nighttime temperatures are remarkable because modern heating systems allow for the automatic reduction of temperatures during the night. For households with high temperatures during night time it was found that the settings of the heating system were not correctly adjusted to the building properties.

[2] To guide the eyes the CO_2 concentrations are connected by a line, although the values are independent from each other.

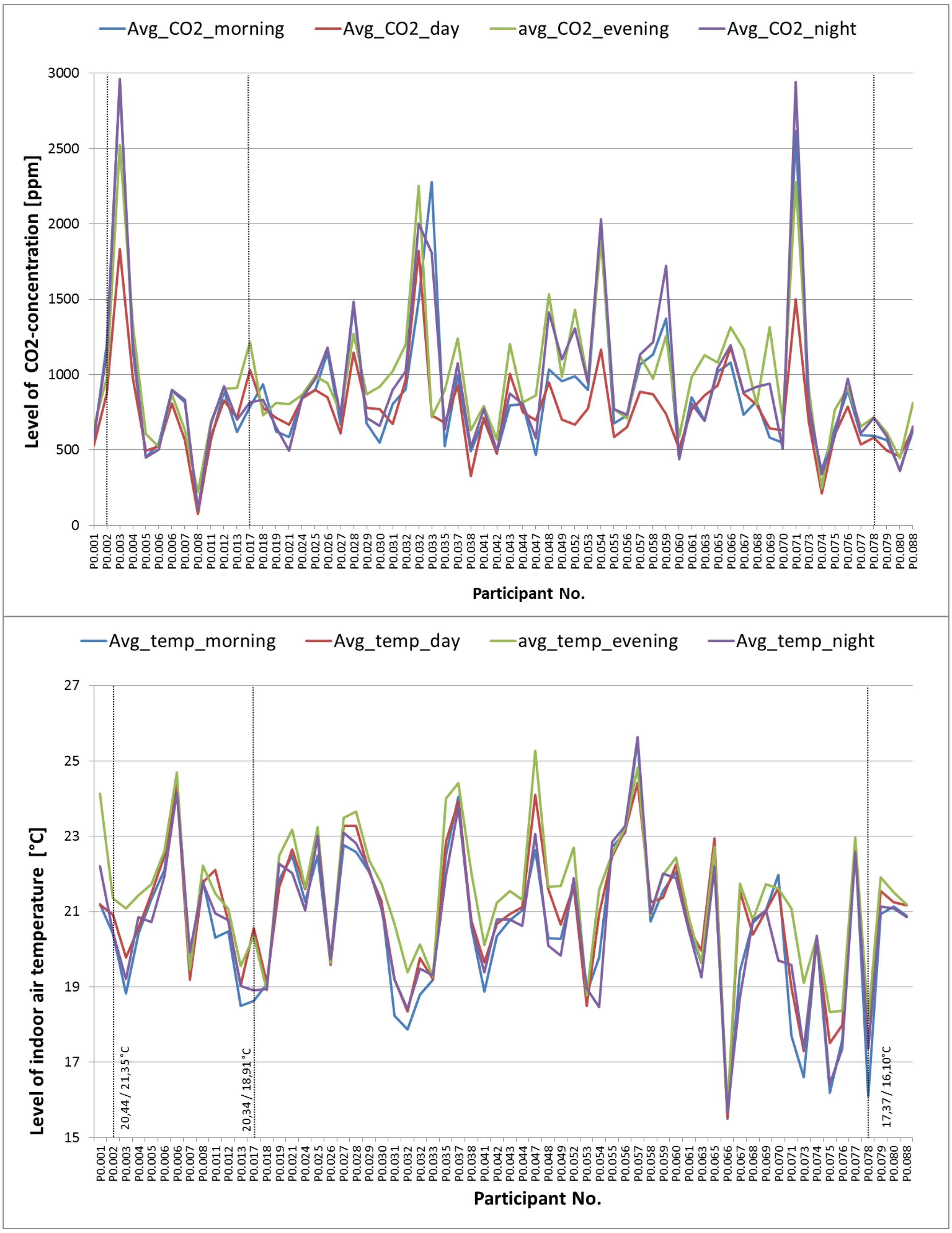

Figure 2: Level of CO_2 concentration and indoor air temperature for different participants and daytime periods

Besides the CO_2 concentration and temperature the energy consumption was measured. To compare measurements in different months, the energy consumption was corrected by using heating degree days and estimating the yearly energy consumption.

Heating degree days were calculated on the basis of German directive VDI 3807 [3] as follows:

$$\mathrm{GTZ}_{t\ 20°/15°} = \sum^{z} (t_i - t_a) \qquad [Kd] \qquad [1]$$

$\mathrm{GTZ}_{t\ 20°/15°}$: *Heating degree days with* $t_i = 20°C$ *and heating limit temperature with* $15°C$

t_i : *Mean indoor air temperature* $[°C]$

t_a: *Mean temperature of outside air on the heating day* $[°C]$

z : *Number of heating days during measurement period* $[d]$

We calculated the heating degrees days for the measurement period and divided this value by the long term heating degree days of the neighbouring city Essen [3].

$$k_P = \frac{\mathrm{GTZ}_{t\ 20°/15°}}{G_{m(Essen)}} \qquad [\%] \qquad [2]$$

k_P : *Part of heating degree days of measurement period to long term heatig degree days*

The forecast of thermal energy consumption for the whole year E_{VgP} can be calculated by

$$E_{VgP} = \frac{E_P}{k_P} \qquad \left[\frac{kWh}{a}\right] \qquad [3]$$

E_P : *Thermal energy consumption during measurement period* $[kWh]$

E_{VgP} : *Forecast of thermal energy consumption for the whole year*

The characteristic value of thermal energy consumption e_P can be calculated as follows

$$e_P = \frac{E_{VgP}}{A_{EP}} \qquad \left[\frac{kWh}{m^2 a}\right] \qquad [4]$$

A_{EP}: *Area of the heated space in the dwelling* $[m^2]$

e_P : *Characteristic value of thermal energy consumption*

This was only carried out for households which have a separate energy meter for heating. Figure 3 shows that the energy consumption is more widely spread than it was found in Figure 1. Due to the calculation procedure this spread is even higher compared to the energy consumption extracted from energy bills, because it is assumed that the consumer behavior is constant over a whole year. In practice, the behavior varies depending on the season. Furthermore, Figure 3shows that the households with automatic temperature control have on average a lower consumption than households without this kind of automation.

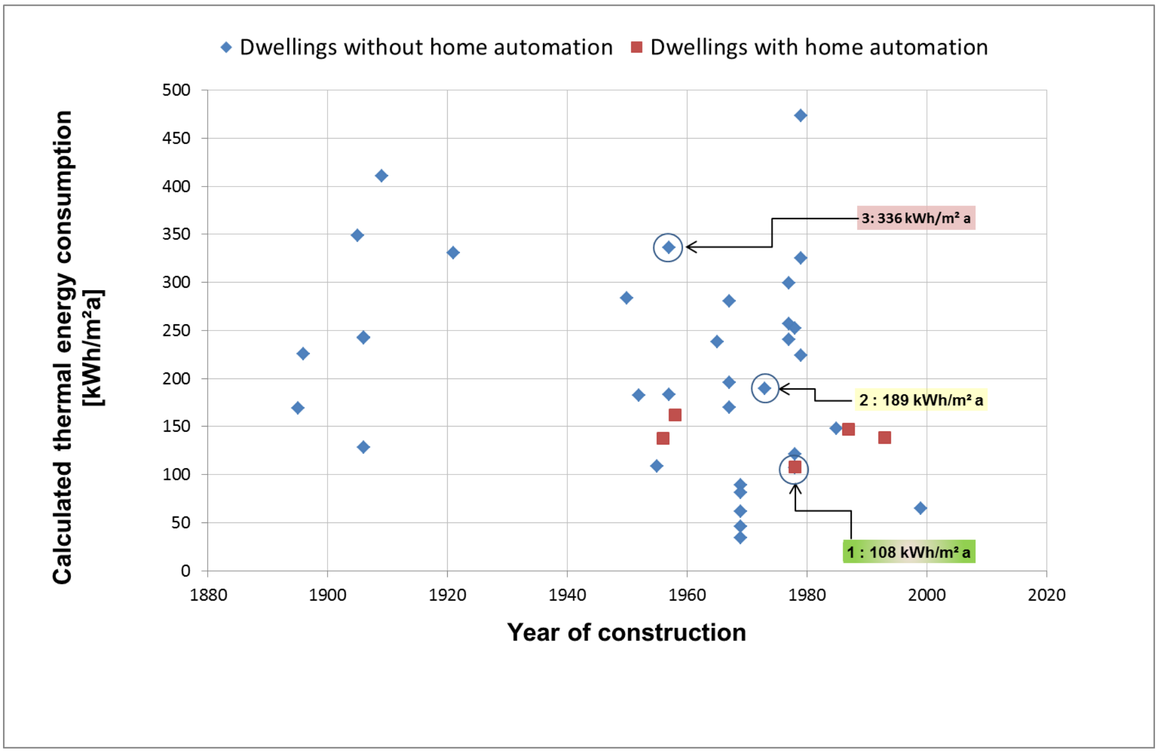

Figure 3: Calculated thermal energy consumption based on heating degree days referring to year of construction of the building

It could be assumed that high room temperatures results in a high energy consumption. But Figure 4 shows that in our measurements there is no strong correlation between room temperature and energy consumption. Furthermore, participants living in older buildings have nearly the same room temperatures in their living rooms as participants in newer buildings.

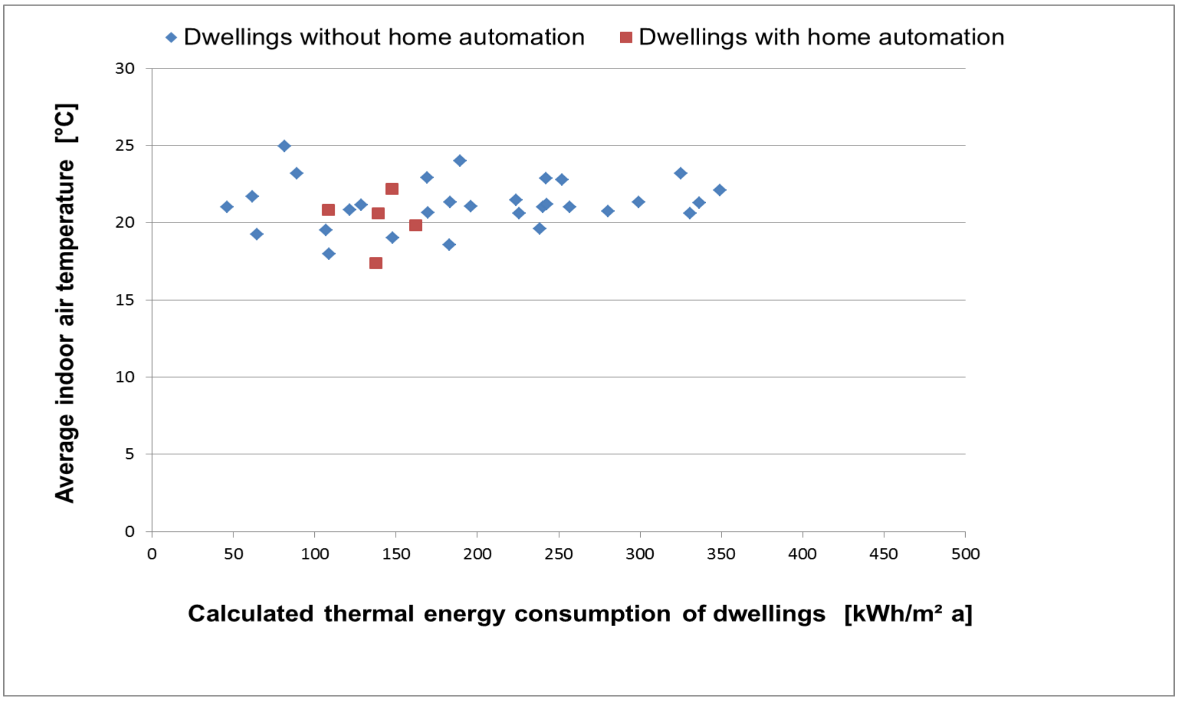

Figure 4 : Indoor air temperature referring to calculated thermal energy consumption (forecast based on heating degree days)

On average the households with automatic temperature control have a lower indoor air temperature than households without automation (see Figure 5).

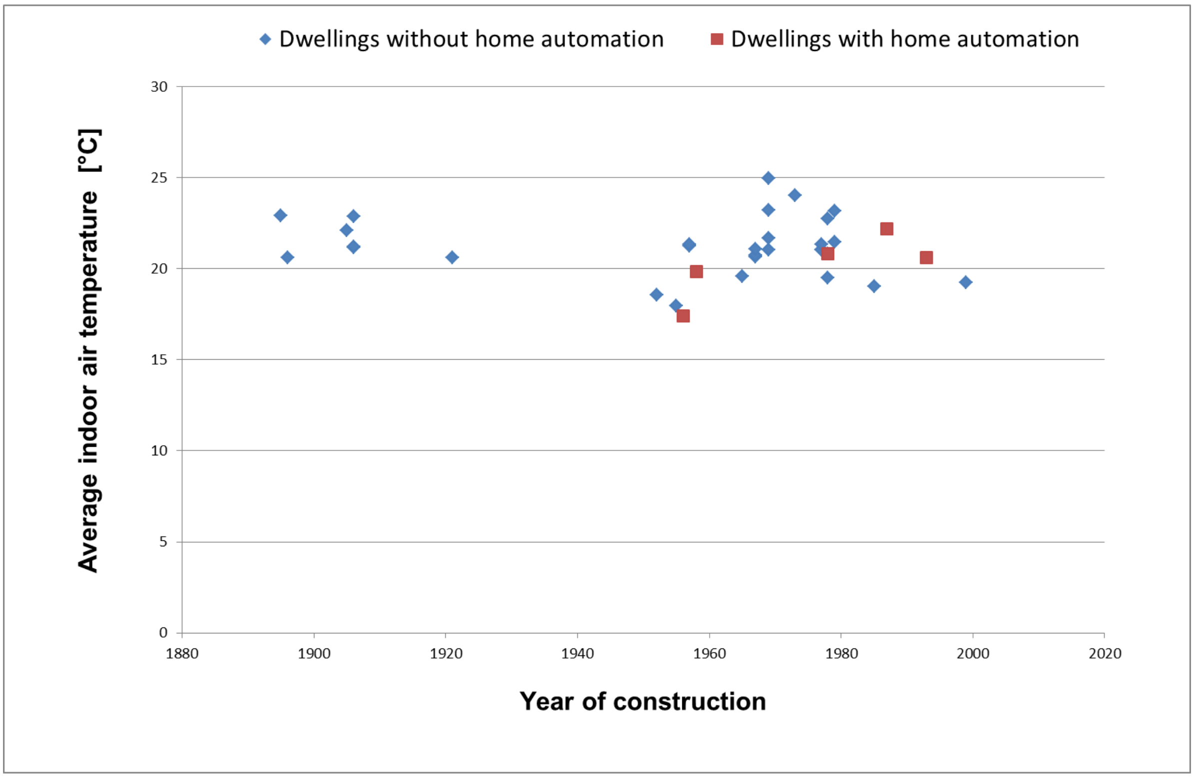

Figure 5: Average indoor temperature referring to year of construction

Furthermore, home automation is not only applied in new buildings but as well in buildings constructed in 1958. These automation systems are based on radio frequency communication and they are especially designed for retrofitting.

Analysis of user behaviour

As room temperature and building properties cannot explain the wide variation in energy consumption we investigated ventilation behaviour more closely. We did this by plotting temperature and CO_2 levels in a heat map which shows days in one column and the temperature/CO_2 value represented in colour. Figure 6 shows households with low energy consumption and home atomised temperature controls (Measurement Point 1 in Figure 3). In the lower part of the Figure 6 one can easily identify the ventilation periods by a drop in CO_2 concentration and decreased room temperature. Furthermore, the quick increase in room temperature indicates that the window is closed after a short time period. The temperature profile shows the impact of the automatic temperature control (increase in room temperature at 7:00 am). In buildings with comparable building characteristics without automatic temperature control the temperature profiles were not as distinctive as shown in Figure 5.

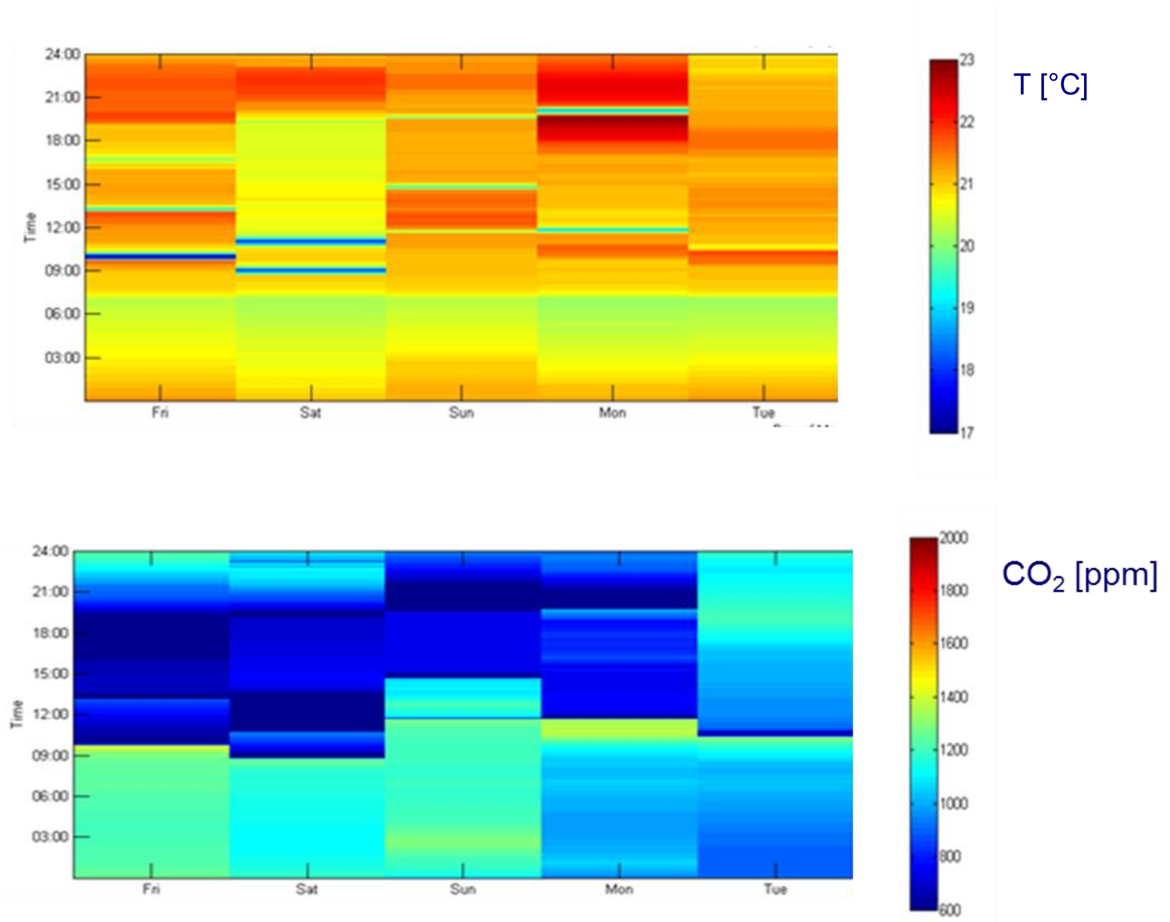

Figure 6: Heat maps showing indoor air temperature (upper diagram) and CO_2-concentration (lower diagram) for the living room of a household with low energy consumption and equipped with home automation.

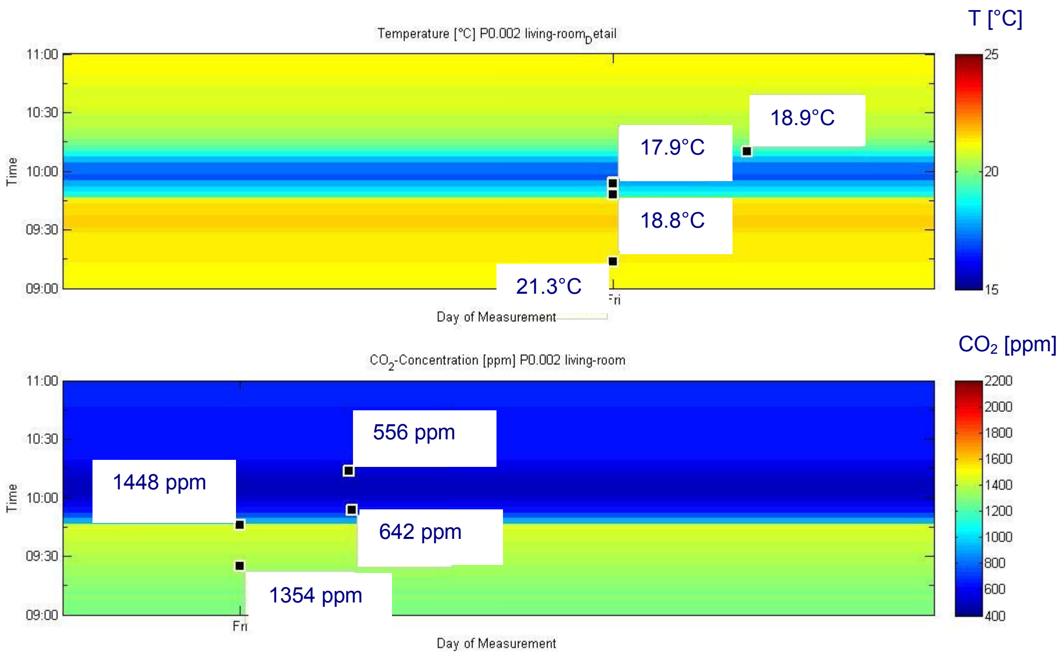

Figure 7: Heat maps detail showing indoor air temperature (upper diagram) and CO_2-concentration (lower diagram) for the same household as shown in Figure 6 for only one day (Friday) from 9:00 am to 11:00 am

Figure 7 shows only a short (3 to 5 minutes) ventilation period is needed to achieve a good indoor air quality indicated through the CO_2-concentration of 642 ppm (starting with 1448 ppm before ventilation). In this, the temperature fell from about 21°C down to 17.9°C. After only 15 minutes the temperature has risen again to a comfortable 20°C.

A different user behavior is shown in Figure 8. The thermal energy consumption of this household is higher than in the previous example and the indoor air temperature is higher (average of 25°C) and constant over the day (measurement point 2 in Figure 3). The ventilation can be recognized by decreasing CO_2 concentrations but the ventilation duration is so short that the room temperature is not significantly affected. The air quality is good only directly after the ventilations.

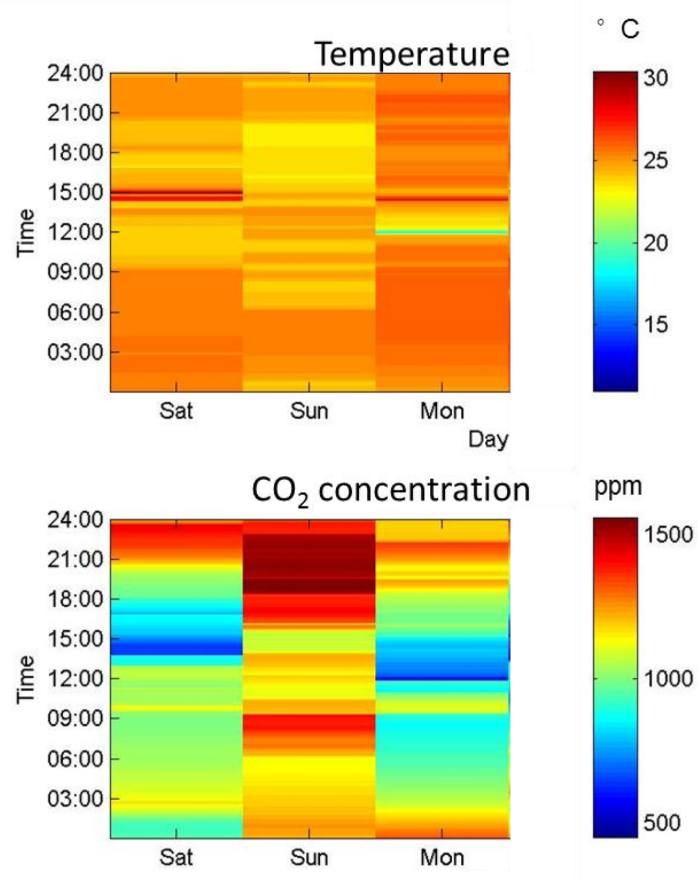

Figure 8: Heat maps showing indoor air temperature (upper diagram) and CO_2-concentration (lower diagram) for a household with mid energy consumption and without home automation

The last example shows a household without home autmation, high energy consumption and high room temperatures (see Figure 9) (measurement point 3 in Figure 3). The ventilation periods are long (over several hours). The room temperature is decreased during this period, but obviously the heating system prevents a drop in room temperature below 22°C. Except for the ventilation periods the CO_2-concentration is too high for a good ambient air quality.

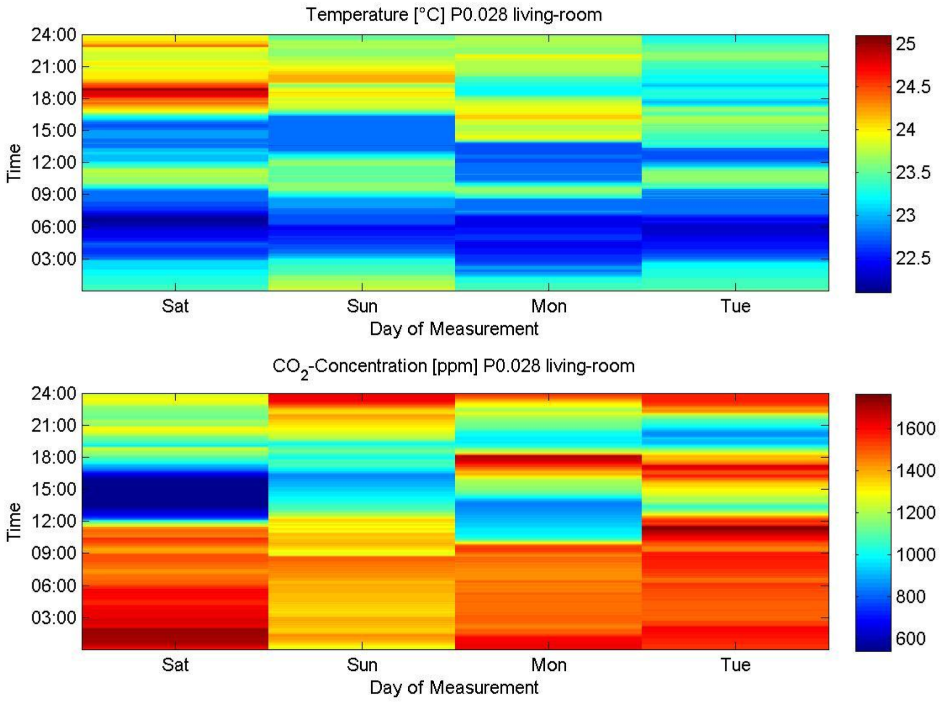

Figure 9: Heat maps showing indoor air temperature (upper diagram) and CO_2-concentration (lower diagram) for a household with high energy consumption and without home automation

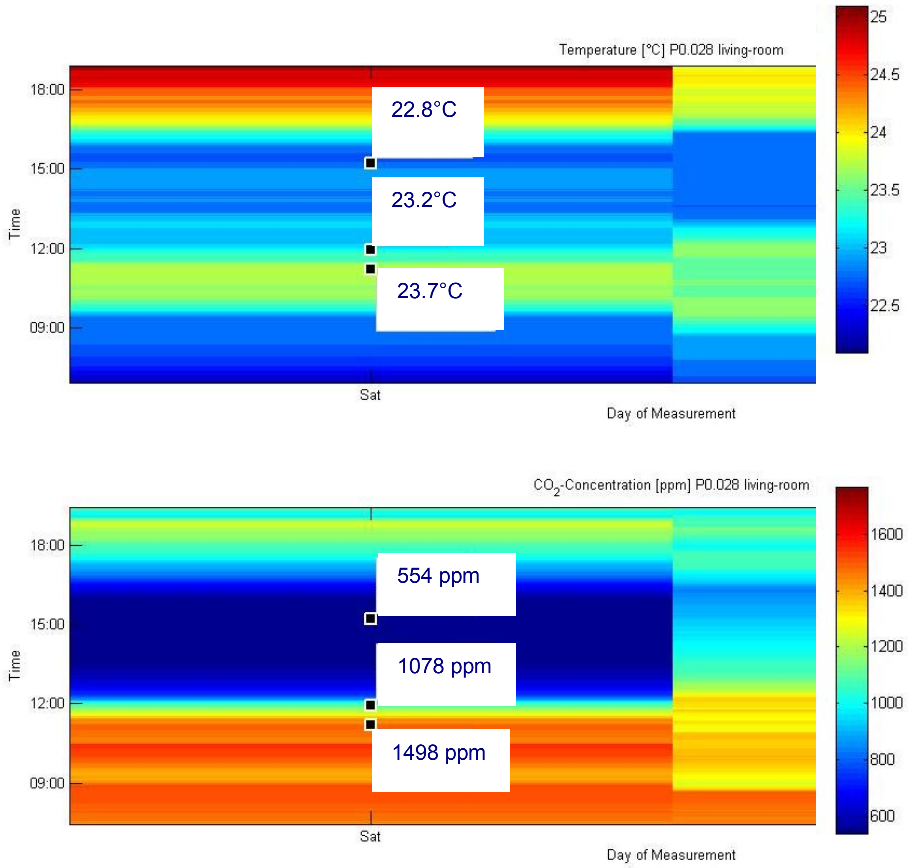

Figure 10: Heat map detail of Figure 9 showing indoor air temperature (upper diagram) and CO_2-concentration (lower diagram) for two days from 9:00 am to 18:00 am.

In Figure 10 is shown the long ventilation period of more than 3 hours. CO_2-concentration decreased from 1498 ppm to 554 ppm. In this time the temperature is falling from 23.7°C to 22.8°C.

Conclusion

Our results show that ventilation habits influence energy consumption more than the temperature level of the room. Good ventilation habits can be termed in case of often but short ventilation periods and bad ventilation habits can be termed such with long periods of ventilation through openig the windows. Automatic temperature control is used to reduce room temperature level during the absence of the user. This improves energy efficency even further. We have found automatic temperature control systems only in 5% of the households we investigated. These households have an energy consumption lower than average and can be characterized by a very efficient ventilation behavior although the automatic temperature control system does not support ventilation. As there are only a small number of households which have such home automation system it can be concluded that they are generally aware of the factors influencing the energy consumption. In case of a wider distribution of home automation systems this cannot be taken for granted any longer. That is why home automation systems and also assistance devices such as ventilation traffic lights, should include a support of ventilation behavior in future.

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Meeting the Challenge of Power Supply Efficiency in Regulations with Low Power Modes

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Abstract

The efficiency of a mains-operated consumer electronics product is determined primarily by three components – the power supply stage, the product's power requirement while providing its primary function, and the power management approach when not providing that function. Many regulations require external power supplies (EPS) to be efficient over a range from 25% to 100% of the power supply's rated output power plus meet a no-load power consumption limit. However, some regulations are now focusing on requiring electronic products to enter into one or more different lower power operating modes depending on the product's typical operating duty cycle. Examples include computers, set-top boxes, and networked appliances. The creation of these new low power modes puts design and performance pressure on the power supply to maintain high efficiency from 100% load to well below 10% load operation.

This paper discusses some key current and proposed efficiency regulations and agreements that focus on low power modes. A recent innovation in power conversion integrated circuits (ICs) that can cost-effectively meet this challenge for internal and external power supplies is presented, including an example design that demonstrates high efficiency across the entire load range. Additional solutions are presented to address power consumption reduction in circuits required to meet noise and power factor requirements.

Introduction

The issue of energy wasted in consumer electronic products has been a topic of discussion for many years. Early studies focused on the most obvious and easiest metric – product standby power loss. An early study in 1999 estimated that up to 10% of electricity consumed by residential products was being wasted while the product was supposedly turned off by the consumer, but was still consuming high levels of energy [1]. Resulting government actions targeted common standby power waste. By 2005, the Korean government had initiated a voluntary program calling for a maximum 1 W standby power consumption limit in many appliances by 2010. The European Commission's (EC) Regulation 1275/2008 regarding Ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment (TREN Lot 6) initially mandated a 1 W limit for many electronic products (2 W if a display was present) by January 2011, reducing those limits 50% by January 2013[2]. Other countries have, or are embracing, similar standby power consumption limits.

Product efficiency specifications also began focusing on the amount of energy consumed in active modes, when the product was providing the function it was designed to provide (i.e. a television displaying video and audio programming). Early program requirements were modal in nature, having both active-on and standby consumption limits. Subsequent versions have combined active-on mode and standby mode(s) power consumption into a single metric referred to as Typical Energy Consumption (TEC) which approximates the total annual energy consumption for an electronic product in its typical daily use.

Regardless of the method, to maximize the energy efficiency potential of an electronic product, one must not only ensure that a product's power management approach allows the product to enter into one or more low power modes depending on reduced user activity, but just as importantly, that the power supply converts the high voltage AC mains to low voltage DC highly efficiently at all operating mode requirements.

Power Supply Efficiency Regulations

The first EPS efficiency regulations focused on reducing power consumption at no-load (i.e. the adapter is plugged in to the mains but not attached to its application). Since then, EPS requirements have become more comprehensive. A good example is the current EC Ecodesign Directive Lot 7 standard (EC No. 278/2009), requiring both a minimum average active mode efficiency (the average efficiency at 25%, 50%, 75%, and 100% load points) and a maximum no-load power consumption[3]. Other regulations, such as the mandatory U.S. EISA 2007 federal standard and the voluntary EC Code of Conduct (CoC), follow the same approach (see Table 1). While the U.S. Department of Energy (DOE) is currently working on tighter EISA 2007 requirements and the EC is in the process of revising Ecodesign and Code of Conduct EPS requirements, current EPS metrics have remained static for the last few years.

Table 1. Current EPS Energy Efficiency Requirements

	EC CoC v4, EC Ecodesign Directive Tier 2 (2011), ENERGY STAR® EPS v2		U.S. EISA 2007
	Standard Voltage PS[1]	Low Voltage PS[1]	
Nameplate Output Power (Pno)	**Min. Ave. Efficiency, Active Mode**	**Min. Ave. Efficiency, Active Mode**	**Min. Ave. Efficiency, Active Mode**
≤ 1 watt	≥ 0.480 * Pno + 0.140	≥ 0.497 * Pno + 0.067	0.5* Pno
> 1 to ≤ 49 watts	≥ [0.0626 * Ln (Pno)] + 0.622	≥ [0.0750 * Ln (Pno)] + 0.561	
> 1 to ≤ 51 watts	≥ [0.0626 * Ln (Pno)] + 0.622 *(Ecodesign only)*		≥ [0.09 * Ln (Pno)] + 0.5
> 49 watts	≥ 0.870	≥ 0.860	
> 51 watts	≥ 0.870 *(Ecodesign only)*		≥ 0.850
	No-Load Power[2, 3, 4]	**No-Load Power[3, 4]**	**No-Load Power**
< 50 watts	0.3 watts / 0.15 watts	0.3 watts / 0.15 watts	0.5 watts
≥ 50 to ≤ 250 watts	0.5 watts	0.5 watts	0.5 watts

Notes: 1. Standard voltage power supply excludes low voltage power supplies which are defined as < 6 volts and ≥ 550 mA, 2. AC-AC is ≤ 0.5 W for all power levels, 3. CoC - No-load spec for mobile handheld battery powered apps ≤ 0.15 W, 4. Ecodesign power levels are ≤ 51 watts and > 51 watts

Internal power supply (IPS) efficiency standards are not that common due to the difficulty in identifying where the power supply output can be tested on the end application circuit board. The most visible IPS efficiency program is the voluntary 80 PLUS computer power supply labeling plan (a computer's IPS is typically a discrete component with easy to identify outputs) which specifies minimum efficiencies at 20%, 50%, and 100% loading. This plan has been adopted by the U.S. Environmental Protection Agency's (EPA) ENERGY STAR® computer program. Version 5, currently in effect, specifies a minimum compliance level of 82% efficiency at 20% load, 85% efficiency at 50% load, and 82% efficiency at 100% load [4].

Emerging Low Power Mode Requirements

Recently, some product efficiency programs have begun including minimum performance requirements for additional lower power modes, based on the product's typical daily duty cycle. Some examples follow.

ICT Equipment (Computers)

The final draft of version 6 of the ENERGY STAR Program Requirements for Computers supports the belief that computers spend a significant portion of their time in an idle state, defined as:

"The power state in which the operating system and other software have completed loading, a user profile has been created, activity is limited to those basic applications that the system starts by default, and the computer is not in Sleep Mode. Idle State is composed of two sub-states: Short Idle and Long Idle" [5]. An example of Long Idle could be 15 minutes after a computer has completed an active workload, the display has entered a low power state (backlight turned off) and hard drive has spun-down.

Idle mode power requirements typically require power below 20% of the power supply's power rating. They are used in calculating the computer's estimated annual Typical Energy Consumption (TEC) in kWh (excluding active mode) as shown below:

$ETEC = 8760/1000 \times (P_{OFF} \times T_{OFF} + P_{SLEEP} \times T_{SLEEP} + P_{LONG\_IDLE} \times T_{LONG\_IDLE} + P_{SHORT\_IDLE} \times T_{SHORT\_IDLE})$

Where P_{OFF} = measured power consumption in OFF mode (W), P_{SLEEP} = measured power consumption in SLEEP mode (W), P_{LONG_IDLE} = measured power consumption in Long Idle mode (W), P_{SHORT_IDLE} = measured power consumption in Short Idle mode (W), T_{OFF}, T_{SLEEP}, T_{LONG_IDLE}, and T_{SHORT_IDLE} are mode (time) weightings as specified in the ENERGY STAR specifications.

This version also includes an incentive to manufacturers who use higher efficiency power supplies than those required for compliance to the program specification. For the first time in a consumer product specification, it highlights power supply efficiency at a 10% load point, approximating Idle Mode power consumption of a computer (see Table 2). The allowance is part of the calculation that sets the computers' maximum allowed TEC.

Table 2. ENERGY STAR Computer V6 Final Draft Power Supply Efficiency Allowance

Power Supply Type	Computer Type	Minimum Efficiency at Specified Proportion of Rated Output Current				Minimum Average Efficiency	$Allowance_{PSU}$
		10%	20%	50%	100%		
IPS	Desktop	0.81	0.85	0.88	0.85	-	0.015
		0.84	0.87	0.90	0.87	-	0.03
	Integrated Desktop	0.81	0.85	0.88	0.85	-	0.015
		0.84	0.87	0.90	0.87	-	0.04
EPS	Notebook	0.83	-	-	-	0.88	0.015
		0.84	-	-	-	0.89	0.03
	Integrated Desktop	0.83	-	-	-	0.88	0.015
		0.84	-	-	-	0.89	0.04

Source: ENERGY STAR Program Requirements for Computers

Power supply efficiency limitations at lower power modes in ICT equipment was noted in a 2012 study published by the International Telecommunications Union (ITU) and the Global e-Sustainability Initiative (GESi). The report, An Energy-Aware Survey on ICT Device Power Supplies[6], covered test results on hundreds of external power supplies displaying different power efficiency levels in both low load condition (10% - 30% of the EPS's maximum rated power) and no-load condition, suggesting that an EPS regulation at low load could translate into reasonable energy savings. This report was also discussed during the 2012 EC EPS CoC meetings which focused on revising the current EPS efficiency agreement (version 4). The version 5 final draft has been published and includes a 10% load efficiency requirement (Table 3) based on the data in the ITU report. Version 5 of the CoC agreement becomes effective in January 2014.

Table 3. Proposed Active Mode Energy-Efficiency Criteria - Code of Conduct Version 5

Rated Output Power (W)	Minimum Four Point Average Efficiency in Active Mode		Minimum Efficiency in Active Mode at 10 % load of full rated output current	
	Tier 1	Tier 2	Tier 1	Tier 2
$0.3 \leq P_{no} \leq 1$	$\geq 0.500 * P_{no} + 0.146$	$\geq 0.500 * P_{no} + 0.169$	$\geq 0.500 * P_{no} + 0.046$	$\geq 0.500 * P_{no} + 0.060$
$1 < P_{no} \leq 49$	$\geq 0.0626*\ln(P_{no}) + 0.646$	$\geq 0.071*\ln(P_{no}) - 0.00115 * P_{no} + 0.670$	$\geq 0.0626*\ln(P_{no}) + 0.546$	$\geq 0.071*\ln(P_{no}) - 0.0014 * P_{no} + 0.570$
$49 < P_{no} \leq 250$	≥ 0.890	≥ 0.890	≥ 0.790	≥ 0.790

Set-top Boxes

A popular consumer product that historically hasn't been allowed to enter into lower power modes is the TV set-top box (STB). This is primarily due to service provider operating system requirements to meet customer expectations (i.e. consumers don't want to wait minutes for an STB to update information to become functional after spending time in a deep sleep low power mode). A Natural Resources Defense Council (NRDC) study revealed that significant energy could be saved if STBs were allowed to enter sleep modes instead of remaining in an active-on mode for 24 hours a day. Work continues between STB manufacturers, service providers, NGOs, and government agencies to allow STBs to go into multiple (light and deep) sleep modes. In Europe, the EC agreed to support an industry-generated Voluntary Agreement (VA) for complex set-top boxes which encourages STB manufacturers to incorporate an Auto Power Down capability, allowing an STB to automatically switch itself into the lowest possible standby mode appropriate within 4 hours of the last user interaction. A similar approach has been published by U.S. manufacturers and service providers. Meanwhile, the current U.S. ENERGY STAR STB program (Version 3) includes a Deep Sleep state defined as a power state that "shall be less than or equal to 15% of the power consumption in On Mode (as measured per the ENERGY STAR test procedure for "Watching Live TV" [PTV]), or 3.0 watts, whichever is greater"[7]. The TEC formula for calculating the STB's power consumption includes the Deep Sleep mode, as shown below.

$$TEC_{PRIMARY} = 0.365\,((T_{TV} \text{ X } P_{TV}) + (T_{SLEEP} \text{ X } P_{SLEEP}) + (T_{APD} \text{ X } P_{APD}) + (T_{DEEP\_SLEEP} \text{ X } P_{DEEP\_SLEEP}))$$

Where T_{TV} is the time coefficient for On mode, P_{TV} is the measured power in On mode (W), T_{SLEEP} is the time coefficient for SLEEP mode, P_{SLEEP} is the measured power in SLEEP mode (W), T_{APD} is the time coefficient for Auto Power Down, P_{APD} is the measured power after Auto Power Down (W), T_{DEEP_SLEEP} is the time coefficient for DEEP SLEEP state, P_{DEEP_SLEEP} is the measured power in DEEP SLEEP state (W)

Networked Standby Power Consumption

Network-connected products are already arriving in our homes and offices. A recent report based on responses from U.S. adult TV owners revealed that American television buyers now are placing increased importance on Internet connectivity. Among US consumers who planned to purchase a television, 30.7 % said they would buy an Internet-enabled (or Smart TV) set, compared to 18 .1% who purchased a TV within the last 12 months[8]. Another example of the emergence of communicative appliances was on display at the recent U.S. Consumer Electronics Show where two of the industry's largest appliance manufacturers showed refrigerators that were able to communicate with the Internet.

While this expanded functionality may be great news for the consumer, it could be troubling news for energy efficiency since networked appliances can stay in an active mode continuously throughout the day, never entering a low power mode when not in use. According to the recent EC Ecodesign Directive networked standby preparatory study (Lot 26), the energy consumption of European household and office equipment that are able to be activated over a network is forecasted to be as high as 90 TWh by 2020 (approximately the annual final electricity consumption of Finland)[9]. As more consumer products are being offered with network connectivity, activity has begun to define low power modes for networked products and appliances. A proposed amendment to the current Ecodesign Directive on Standby and Off-mode power consumption (EC No. 1275/2008) addresses networked standby products and divides products into two groups – those with High Network Availability (HiNA) and those without. HiNA equipment resumes functionality within milliseconds; non-HiNA equipment resumes functionality within more than one second (generally within 5 seconds). It's estimated that the amendment could encourage an increased adoption of lower power technologies, resulting in an estimated energy savings of 36 TWh by 2020[9].

If approved, the maximum networked standby power consumption requirements would become effective in two tiers as shown in Table 4.

Table 4. Proposed Limits of Ecodesign Lot 26 - Networked Standby Power Consumption

	January 1, 2015	January 1, 2017
Products with HiNA	12 W	8 W
Products without HiNA	6 W	3 W

Based on the above examples, it's apparent that efficiency regulations going forward could include more requirements to allow electronic products to enter lower and lower power modes when they're not providing their intended function. In order to maximize overall system efficiency, the power supplies used with those products will need to deliver high efficiency at those lower power levels.

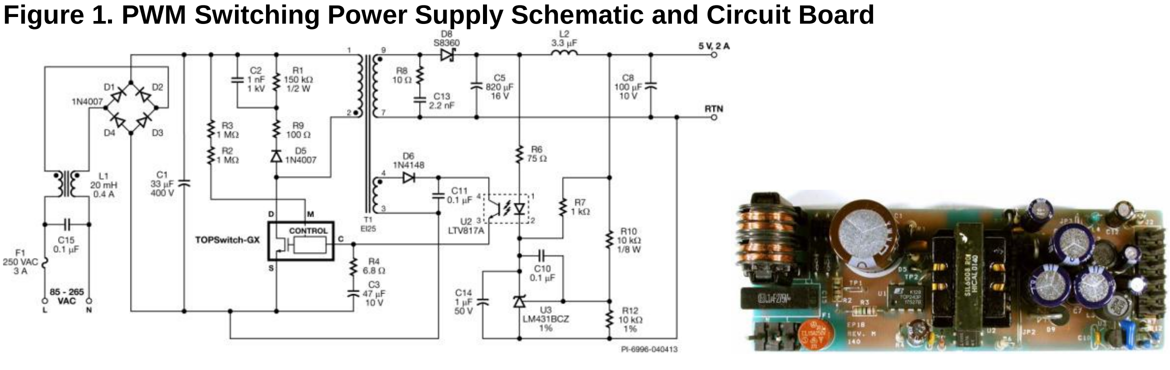
Enabling High Efficiency, From High to Low Load

Changing from linear to switchers is no longer enough

Designing highly efficient power supplies to meet power supply efficiency requirements has become more challenging as requirements have evolved. In the beginning, just changing from a linear-based power supply to a switching power supply was a quick way to reduce standby power consumption as well as improve active mode efficiency. But simply changing to a switching approach doesn't guarantee compliance with emerging standards.

Let's look at the performance of a 10 year old "energy-efficient" switching power supply built with a power conversion integrated circuit that was introduced in the early 2000's (and is still available). The circuit (EP-18), shown below, provides 10 W of output power.

Figure 1. PWM Switching Power Supply Schematic and Circuit Board



The power conversion IC (TOPSwitch™-GX) is a monolithic chip which combines a standard pulse width modulation (PWM) controller (switching at 132 kHz) with a high voltage power MOSFET plus a suite of protective functions such as under/over voltage protection, programmable current limit, thermal shutdown, and reduced Electromagnetic Interference (EMI) EMI can cause problems with other products if allowed back on to the AC mains. The output is regulated using an isolated winding on the secondary side of the power transformer (T1), an opto coupler (U2), a voltage reference IC (U3) and some miscellaneous resistors and capacitors.

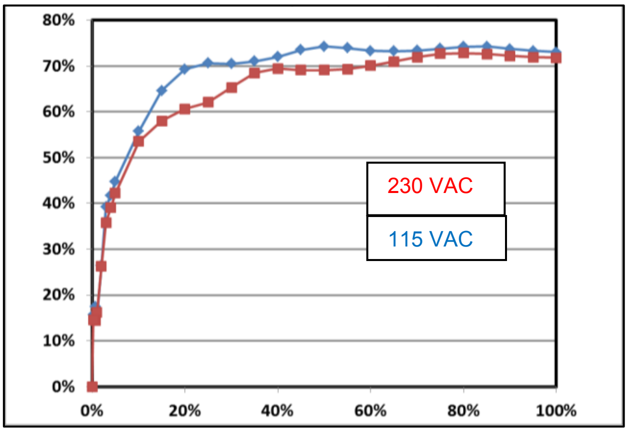
The efficiency test data summary below confirms that even though this power supply was designed in 2001, well before power supply efficiency regulations were in effect, the IC's PWM switching profile enables good efficiency that complies with both the 25% to 100% load average active mode efficiency and no-load power consumption requirements of the current U.S. EISA 2007 EPS efficiency standard and very nearly meets the EC Ecodesign Directive's EPS 2010 tier 1 levels.

Table 6. Active Mode Efficiency and No-load Power Performance of PWM EPS

	Requirement		EP-18 (115 VAC)		EP-18 (230 VAC)	
	Ave. Eff. (%)	No-Load (W)	Ave. Eff. (%)	No-Load (W)	Ave. Eff. (%)	No-Load (W)
EISA 2007	70.7	0.5	72.9	0.368	-	-
Ecodesign (Lot 7, tier 1)	70.7	0.5	-	-	68.9	0.418

However, this power supply becomes significantly less efficient below 25% load as shown in Figure 2 (X-axis is load and Y-axis is efficiency). For this circuit, the efficiency drops over 15% between 100% load and 10% loading.

Figure 2. EP-18 Efficiency Curves

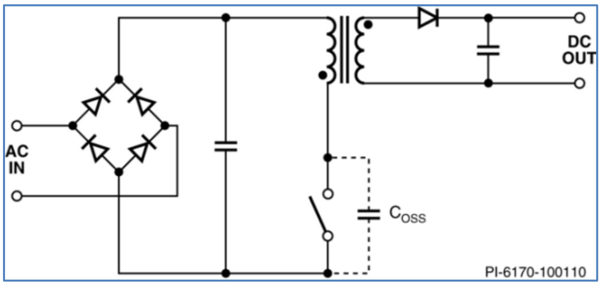


This low load efficiency droop effect was also observed and discussed in the previously mentioned ITU and GESi report. In that 2012 report, a number of graphs are presented that show recent EPS performance curves of similarly rated EPSs with close efficiency at higher loads but with much different efficiency at lower loads.

A New Switching Approach to Improve Efficiency

To address the problem, one needs to focus on the areas of loss in the power supply's output transistor. Regardless of the semiconductor technology used for the switching transistor (represented in Fig. 3 as a simple on-off switch), the two components of power loss are conduction losses (determined by $I^2R_{DS(ON)}$ where I is the current flowing through the transistor and $R_{DS(ON)}$ is the output resistance of the transistor) and switching losses. Switching losses are further broken down into capacitive and cross over losses. Capacitive losses are determined by ½ $C_{OSS}V^2f$, where Coss is the output capacitance of the transistor, V is the voltage across the transistor, and f is the switching frequency. Cross over losses are determined by the switching speed of the MOSFET, voltage, current being switched and frequency. Critically, both forms of switching loss are a function of switching frequency.

Figure 3. Simplified Power Switching Circuit



In lower power modes, reducing transistor switching loss is key in maintaining efficiency. One approach is to vary the frequency and waveform of the signal turning the switch on and off, depending on load level requirements. Another is by using a simple ON-OFF signal to turn the switch on and off, skipping cycles when less power is needed. Both can be used to successfully increase a power supply's efficiency at very different power levels.

To meet emerging efficiency regulations, a new controller was developed based on an innovative multi-mode control engine, delivering high efficiency continuous conduction mode (CCM) operation from high to low loads without the efficiency limitation of other switching modes or problematic audible noise. An enhanced peak current mode PWM control scheme is used that automatically adjusts to maintain high efficiency as power requirements change, based on a compensation input voltage which mirrors changes in the power supply's output power. This technology is the core of a new generation power conversion IC family known as LinkSwitch™-HP[10]. The IC is made up of a single silicon chip monolithically integrated controller and high power MOSFET (725 V), assembled in a low cost plastic package. It's capable of delivering up to 90 watts for a wide range of consumer and office applications. As with the TOPSwitch IC used in the previous power supply, it also includes comprehensive protective features including under/over voltage protection, programmable current limit, reduced EMI, and thermal shutdown.

Figure 4. LinkSwitch-HP Switching Waveforms

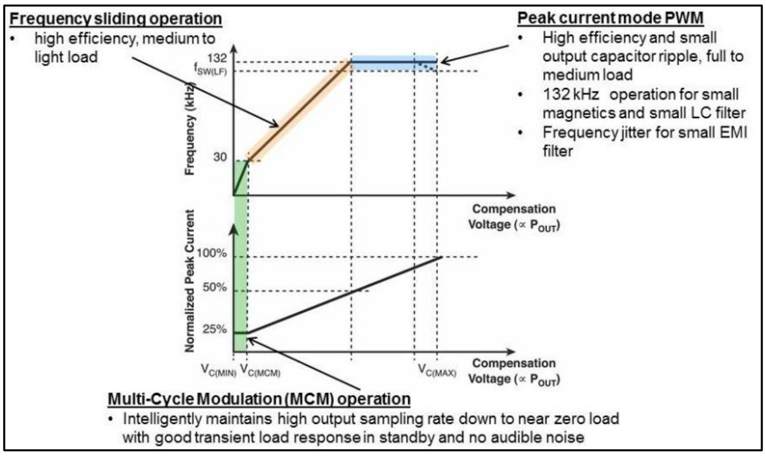
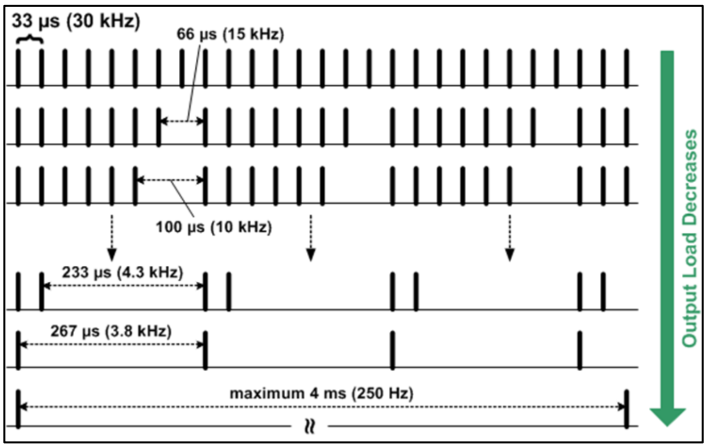


Figure 4 illustrates the switching technique incorporated in the new device. The top graph plots switching frequency versus the compensation voltage; the bottom graph plots normalized peak output current versus the compensation voltage.

Moving right (high power) to left (lower power), the switching operation begins basically as a pulse width modulated (PWM) switcher running at 132 kHz. This is a common switching technique, found in many switching power supply designs such as the previous example, providing the benefit of good efficiency with small magnetics. During this period (represented in blue), the output voltage and switching frequency remain constant, while the output current decreases to satisfy lower load power requirements. At approximately 50% load, the voltage on the compensation pin causes the controller to automatically shift into a frequency reduction operation, maintaining efficiency from medium to light loads by reducing MOSFET switching losses. When voltage on compensation pin reaches $V_{C(MCM)}$ (about 1.25 V), the peak drain current is reduced to 25% of programmed value with the switching frequency at approximately 32 kHz.

Figure 5. MCM Mode Operation



At approximately 5% load, the peak output current of the device is fixed at 25% of the full load current limit and the device automatically enters into multi-cycle modulation mode (MCM). From that point down to near zero load, the device, operates in pulse mode shown in Fig. 5. During MCM operation, the controller intelligently maintains a relatively high output sampling rate while reducing the average switching frequency to keep the output voltage in regulation. Switching at 25% of the set current limit dramatically reduces the transformer core flux density, which along with the intelligent MCM operation, reduces audible noise well below acceptable levels.

Extremely low input power consumption at very low outputs (i.e. approaching and including no-load) of less than 30 mW is possible due to two features of the device: 1) a sampling rate maximum MCM off-time $T_{MCM(OFF)}$ = 4 ms (typ.) and 2) the inclusion of primary side regulation (PSR) in providing voltage control feedback. PSR eliminates the need (and cost) for the external voltage reference IC, optocoupler, and other components found in the first EPS example. This is especially critical for the highest efficiency at ultra-low output levels.

Power Supply Performance Results

To demonstrate the efficiency performance of the new device, a 30 W power supply was designed and built as shown in Figure 6[11]. The design goal was to cost-effectively achieve compliance with all current EPS regulations, plus maintain efficiency at lower and no-load power modes to meet proposed regulations.

Figure 6. Multi-mode Switching Power Supply Schematic and Circuit Board

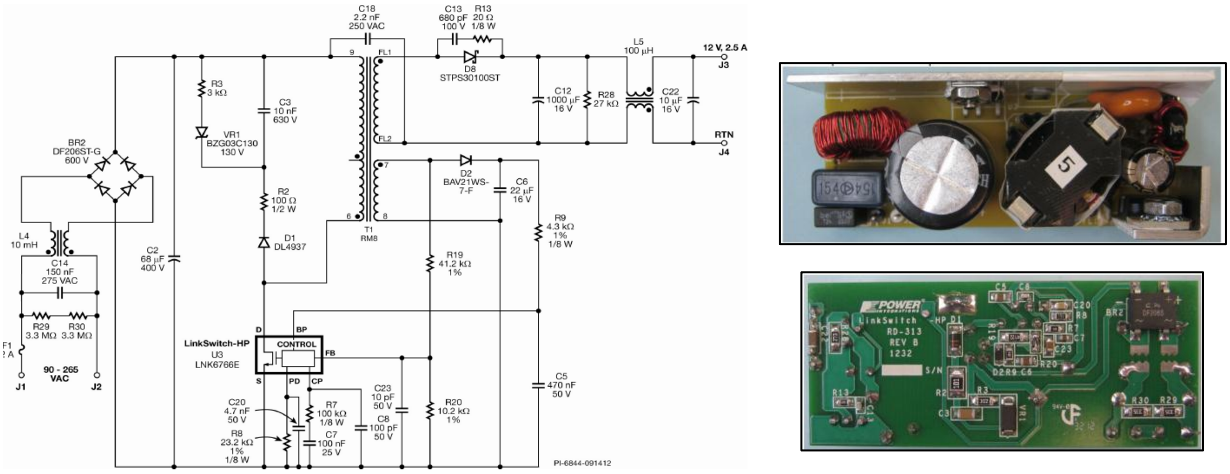
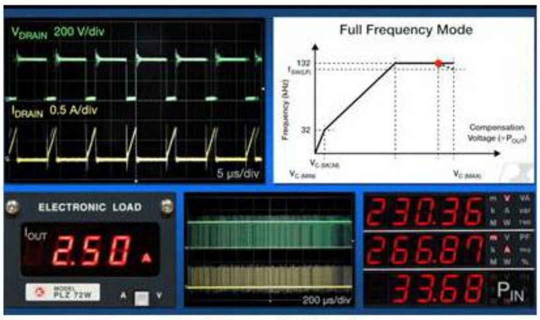
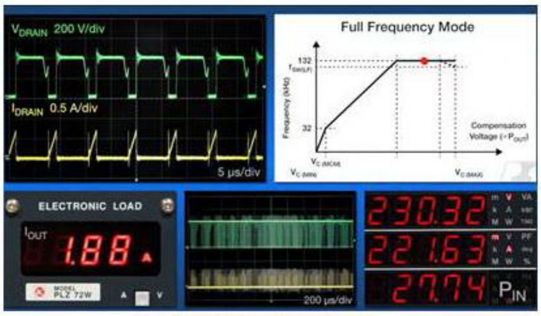


Figure 7 illustrates the power supply's multi-mode switching waveforms. At full load, the controller operates in 100% PWM mode at 132 kHz. As the load decreases down to ~ 50%, the number of switching cycles remain the same, but the duty cycle shrinks (upper yellow waveform) due to the reducing output current. Just below 50%, the controller shifts to frequency sliding operation with reduced load, down to 32 kHz, as seen in the 25% and 10% load graphs, resulting in fewer switching events and reducing switching losses (upper yellow waveform). The second LinkSwitch-HP operation switch point (~5% load) causes the switching mode to change to MCM with packets of switching cycles switching at hundreds of hertz compared to the 32 kHz previously.

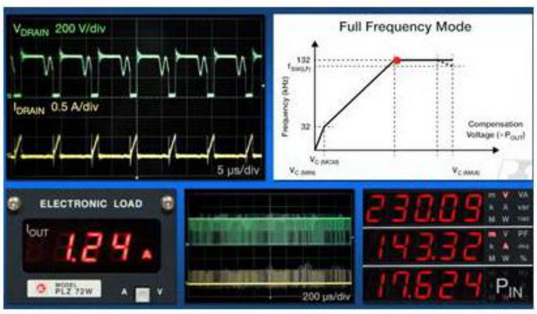
Figure 7. Power Supply Multi-mode Switching Waveforms vs. Load



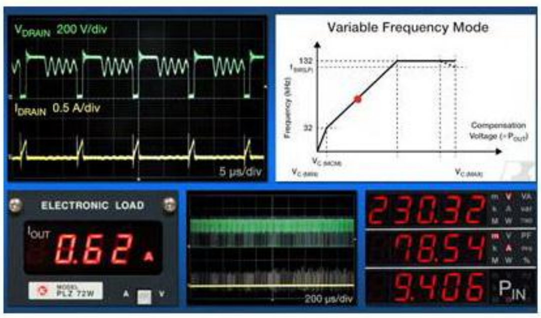
a. Full Load Mode



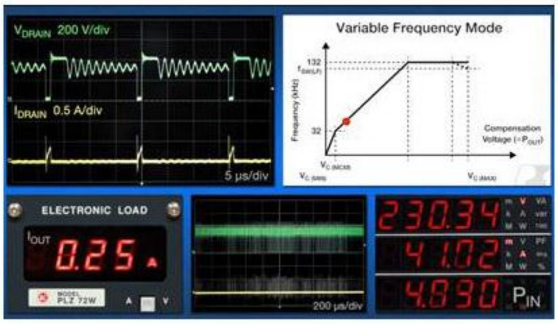
b. 75% Load



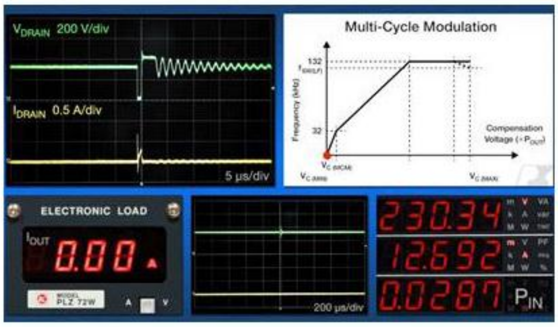
c. 50% Load



d. 25% Load



e. 10% Load



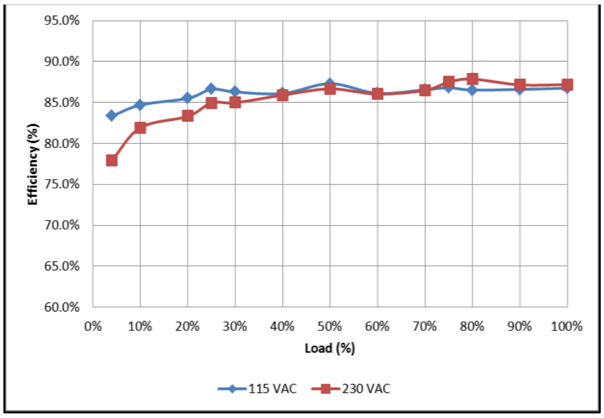
f. No-Load Mode

Regarding efficiency performance, this power supply easily meets all the EPS requirements of EISA 2007, the Ecodesign Directive (Tier 2), and the final draft of the upcoming CoC. The average active mode efficiency between 25% and 100% loading is just under 87% at 230 VAC and just under 88% at 115 VAC.

Table 7. Multi-mode Supply Active Mode Efficiency and No-load Power Performance

	Requirement		(115 VAC)		(230 VAC)	
	Ave. Eff.	No-Load	Ave. Eff.	No-Load	Ave. Eff.	No-Load
EISA 2007	80.6%	0.5 W	87.7%	0.018 W	-	-
Ecodesign (Lot 7,tier 2)	83.49%	0.3 W	-	-	86.9%	0.029 W
EC CoC (ver 5, tier 1)	85.9%	0.15 W			86.9 %	0.029 W

Figure 8. Multi-mode Power Supply Efficiency



Importantly, Figure 8 reveals that the efficiency at lower loads has not appreciably dropped. At 230 VAC, this power supply is still well over 80% efficient at 10% loading. Unlike the first circuit with approximately a 15% drop in efficiency between full load and 10% load, the LNK-HP circuit drops only ~2% at 115 VAC and only ~ 5 % at 230 VAC.

No-load power consumption is remarkably low, < 30 mW at 230 VAC, thanks to the IC's pulse skipping technique and PSR.

Figure 9. No-Load Power Performance

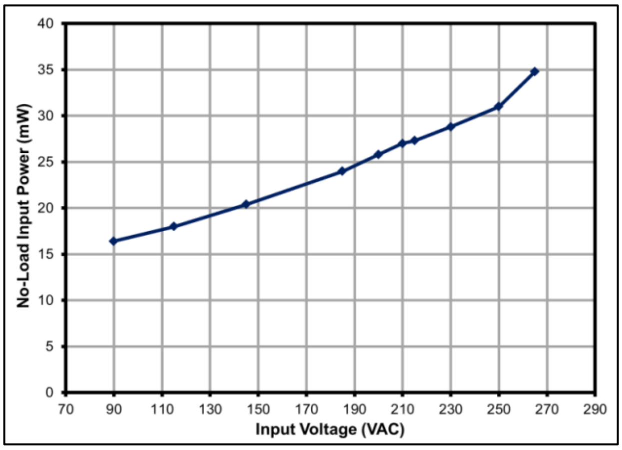
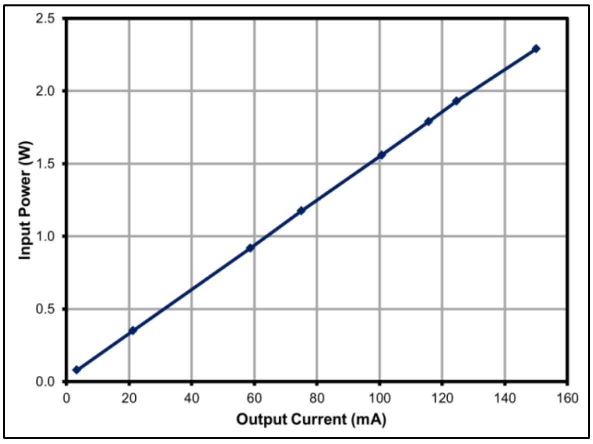


Figure 10. 230V - Input Power vs. Output



A check of available output power at EC Ecodesign Directive Regulation 1275/2008 (Lot 6) standby power levels also reveals excellent performance. Using Figure 10, output power can be calculated by multiplying the output current (X-axis) corresponding to key input power points (i.e. 1 W, 0.5 W) by 12 volts (the power supply's output voltage). At 1 W power consumption, this 30 W power supply operates at ~75% efficiency, providing ~ 750 mW of usable power to an application in a very low power mode. At 500 mW input, 360 mW is available, for a respectable efficiency of 72%.

Additional Efficiency Enhancements at Very Low Power

There may be circumstances where achieving very low power consumption is difficult due to power consumption from additional circuits/components that are added to meet required safety, noise, or power factor regulations. Two recent "auxiliary" ICs have been introduced to address these situations.

Applications such as motor drives, domestic appliances, and industrial equipment can generate EMI. To meet EMI standards (EN 55022B and CISPR22B) a filter stage is inserted at the AC input. As part of this filter, capacitors are commonly placed directly across the AC input terminals. Unfortunately, the energy stored in the capacitor(s) is present across the input prongs of the power supply and could shock a consumer after unplugging the product. To prevent this risk, safety agencies mandate that capacitors with values above 100 nF be discharged automatically within <1 second (UL1950/IEEC950). This is typically achieved by placing discharge resistors directly across the capacitor, resulting in a constant power loss while plugged in. For example, a power supply that uses a capacitance of 1 µF across the incoming AC will require a resistor which dissipates 53 milliwatts at 230 VAC, independent of the output load. With more stringent no-load and standby input power requirements, this power loss can become a significant portion of the overall power budget.

CAPZero™ is a self-contained, two-terminal IC that can be added to any power supply with discharge resistors to completely eliminate power lost in the components. It's a simple product that easily meets safety requirements and helps in achieving the lowest possible no-load input power. CAPZero acts as a smart switch when placed in series with the discharge resistors. The switch is open while the AC is connected, eliminating the constant power loss through the discharge resistors. When the AC is disconnected, the switch is automatically closed, safely discharging the capacitor through the resistors.

Power Factor Correction (PFC) circuitry is often required to improve the supply's apparent power to real power ratio. Making the power factor ratio as close as possible to unity brings the voltage and current in phase and enables efficient delivery of electrical power to the consumer. An active PFC circuit (consisting of additional semiconductor switches and control electronics) is typically inserted after the power supply's input rectifier bridge. Most PFC controllers monitor DC Bus voltage and current to control supply operation, using a resistor chain between the high voltage rail and a low voltage monitoring pin. These sense resistors burn constant power whenever high voltage is present, even when the controller they're connected to has been disabled during standby. Adding an active PFC circuit can add ≥100 mW per resistor chain, significantly increasing standby input power. To reduce standby power consumption in PFC circuit high voltage bus sense resistors, the SENZero™ IC was developed. It eliminates wasted power by placing a smart switch in series with the sense resistors to effectively disconnect them when the main switching is deactivated, eliminating sense resistor current when it's not required. It can easily save over 100 mW of power consumption. SENZero's integrated MOSFETS have ultra-low leakage, allowing the three channel device to consume just 0.79 milliwatts of total standby power.

Conclusion

As consumer electronic products increase in functionality and network-ability, energy efficiency regulations are expected to continue to evolve and include requirements for products to enter additional lower power modes when not providing their primary function. To maximize overall efficiency, the product's power supply will need to be designed to deliver high efficiency at those lower power levels. The technology to accomplish this is currently available with power conversion ICs that automatically modify their switching characteristics to maintain good efficiency from full load to no-load. Additional ICs are available that target power consumption caused by supplemental circuits required to comply with non-efficiency regulations. Future power conversion ICs could tailor their operation to target efficiency at specific load points as they become part of efficiency regulations (i.e. 10% load). On-going material and circuit design innovation in the power conversion area should continue to reduce energy waste in electronic products.

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Battery Charger Systems: The Next Cross-cutting Policy Opportunity to Address Plug Load Energy Use

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Abstract

By rough estimate, 2 billion electronic products that contain battery charger systems (BCSs) are currently in use in Europe. Bar code scanners, electric fork lifts and carts, cordless and cellular phones, and cordless appliances and tools are all examples of products that rely on BCSs. These products offer substantial economic and environmental advantages over those with throwaway batteries and are more convenient than corded products.

Efforts to improve the efficiency of ac-dc power conversion through internationally harmonized external power supply (EPS) minimum energy performance standards (MEPS) have resulted in substantial savings. Battery chargers represent another horizontal energy efficiency policy opportunity that can build on the success of EPS MEPS and again allow policymakers to address the energy use of many product types at once. Energy savings from BCS MEPS in California are expected to be 2 TWh per year after total stock turnover, equivalent to nearly one medium-sized coal power plant (1 Rosenfeld), about the same amount of electricity used by all the homes of Cyprus.

This paper provides a summary of the current battery charger policies in the U.S., including the MEPS adopted by the California Energy Commission in 2012 and those currently under consideration by the U.S. Department of Energy (DOE), as well as a discussion of the advantages and disadvantages of each U.S. policy approach. The authors also discuss possible interaction with EPS and European standby policy.

Introduction

In 1974 California's legislature created the California Energy Commission (CEC) with the primary mission of developing the state's energy policy and plan. One of its many activities in support of that mission is to routinely develop, evaluate and adopt new appliance and lighting minimum energy performance standards (MEPS). Its authority is typically limited to those appliances and lighting applications that are not already covered by U.S. federal MEPS and only to measures that deliver cost-effective savings. This framework encourages California to be a "scout" for emerging MEPS opportunities that are not yet addressed by many policymakers.

The CEC has adopted more than 30 appliance standards since its inception, some of which have helped to lay the foundation for U.S. and even international MEPS. The initiative to reduce external power supply (EPS) energy use is a successful example of California stakeholders working with national and international partners to support a common testing and policy approach. Harmonization sent a clear message to Asia-based manufacturers regarding testing and requirements, supporting compliance in all jurisdictions and reducing the testing and design burden on manufacturers.

A similar harmonization opportunity exists for battery chargers. The CEC recently adopted the world's first battery charger system (BCS) MEPS that addresses many domestic, commercial, and industrial BCSs. Like external power supplies, the domestic systems are often manufactured in Asia, branded, and then distributed world-wide. They are fundamentally a portable power system (like EPSs), and they represent a relatively new opportunity without policy or test procedure precedent that can make harmonization more difficult to achieve. Given the large energy savings opportunity associated with battery chargers, leveraging the current U.S. policy activity to deliver energy savings outside of the U.S. is a promising opportunity to globally address electronics energy use.

Table 1: Current and Planned Electronics MEPS in California

Product Group	California Annual Energy Savings (TWh/year)*	Compliance Date	Other policy efforts supported by California MEPS action
External power supplies [1]	1	July 1, 2006 and July 1, 2008	International harmonization on metrics, test procedure and MEPS
Televisions [2]	6	January 1, 2011	Improved U.S. DOE test procedure
Battery Chargers [3]	2	Feb 1, 2013	Supported the development of a federal test procedure that included active mode
Pay television set-top boxes [4]	0.5	Currently under consideration by the California Energy Commission	
Residential network equipment [4]	0.4		
Desktop and laptop computers[4]	2		
Computer monitors [4]	1		
Game consoles [4]	0.6		

* Energy savings in California after complete stock turnover; table does not include digital television adaptors, which were an interim product developed for the U.S. transition to digital television broadcasting.

BCS Overview

While many modern electrical appliances receive their power directly from the utility grid, a growing number of everyday devices require electrical power from batteries in order to achieve greater mobility and convenience. BCSs are used to recharge these batteries when their energy has been drained. BCSs take high-voltage alternating current from the wall outlet and convert it into lower voltage direct current that can be used to charge common battery chemistries. This basic function is common to all battery charging systems, regardless of whether the battery-powered product is a cordless shaver, an uninterruptible power supply (UPS), or an electric vehicle. These systems are employed by a variety of end uses, from low power cell phones to high power industrial forklifts (also known as lift-trucks).

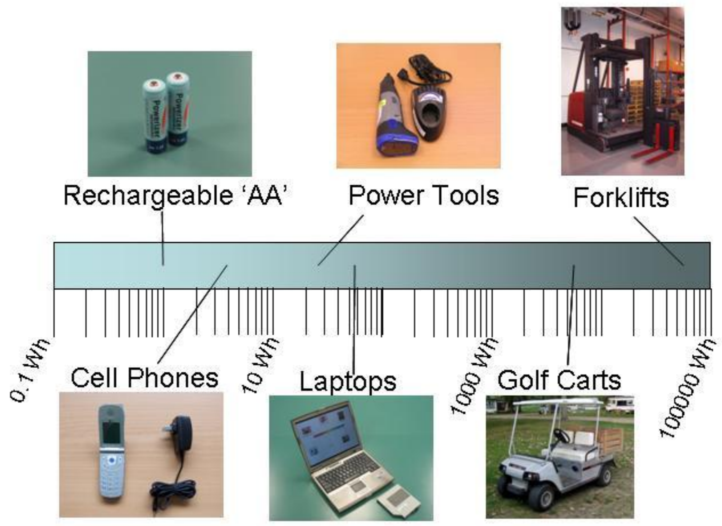

Figure 1: Various battery powered devices and their relative battery capacities [5]

Half of all electronic products in the U.S. contain BCSs and these systems draw nearly one-fifth of total energy used by electronic products in the U.S. [6]. Improving the efficiency of these systems is second only to ac-dc power supplies as a key horizontal strategy for improving the efficiency of all electronic products [7].

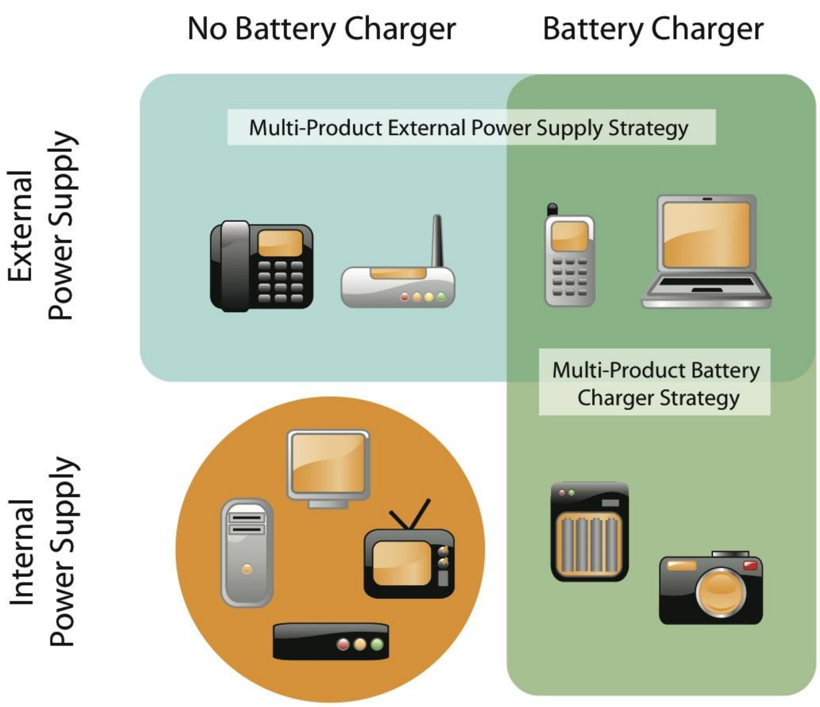

Figure 2: Battery chargers as the second opportunity to improve the efficiency of multiple electronic products [8]

All BCSs have three functional components:

- A power supply (either internal or external) that converts high voltage ac (either single phase or three phase) to low voltage dc;
- Charge control to regulate electric current going to the battery during charge and battery maintenance modes;
- A battery that stores energy for the end use product.

Battery chargers have three primary modes of operation: charge mode, maintenance mode, and no-battery mode (Figure 3). During charge mode, the battery charger delivers energy to the battery to bring the battery from a state of discharge to a state of charge. When the battery is at or near 100% capacity, many battery chargers will continue to deliver some amount of energy to the battery to counteract the effects of battery self discharge. This mode of operation is referred to as battery maintenance mode. In no-battery mode, the battery is removed from the power supply or charger cradle (e.g. when a cordless phone or power tool is removed from its charging base). The battery charger may still draw power in this mode even though no battery is connected to the system.

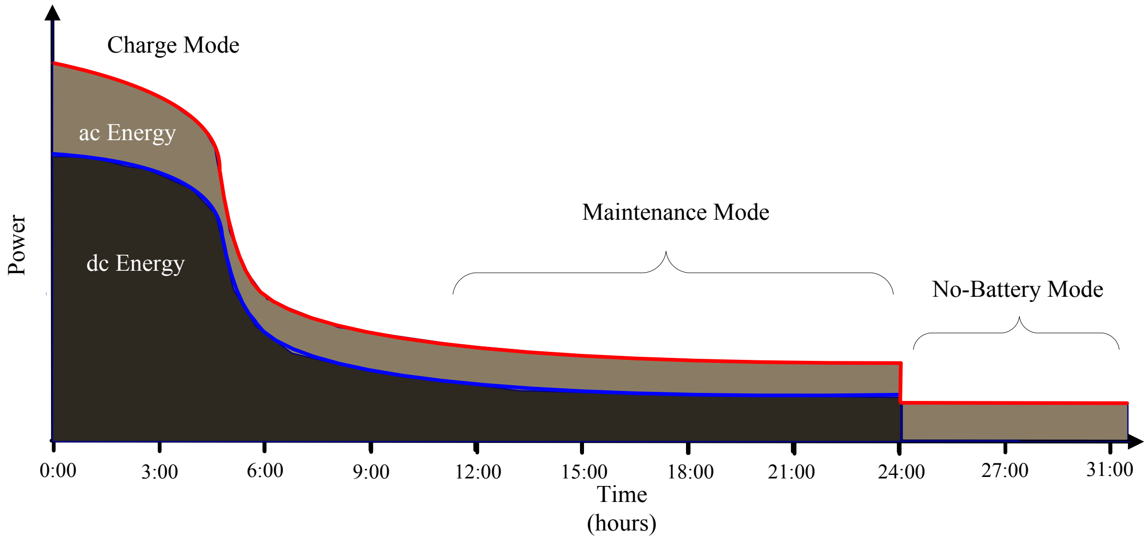

Figure 3: Switch-Mode Battery Charger Power Profile

Efficiency differences are evident, even when comparing nearly identical products. Figure 2, below, shows test results of two, 7 volt lithium ion power tools available commercially. The charger on the left is a linear design, which is 24% efficient over a 24-hour charge and maintenance cycle (see "Test Standard"). The charger on the right is switch-mode design and is nearly twice as efficient over the same 24-hour period with significantly less energy used in battery maintenance and no-battery modes.

	
Tool Charger	Tool Charger
Li-Ion battery	Li-Ion Battery
24% 24-hr Efficiency	43% 24-hr Efficiency
Maintenance Power: 0.5 W	Maintenance Power: 0.2 W

Figure 3: Power tool efficiency comparison [9]

Domestic battery charger systems can be cost-effectively improved through three key approaches:

Increasing the efficiency of ac-dc power conversion. Many of the internal and external power supplies for today's domestic BCSs do not yet incorporate best-in-market technology for power conversion. While some battery chargers that operate with external power supplies incorporate higher efficiency designs that meet external power supply MEPS, battery chargers with internal power supplies are not subject to any requirements. In some battery charger system markets (such as portable cordless power tool markets), there are no market drivers to improve the power supply efficiency in the absence of MEPS.

Improving charge control, with an emphasis on effective charge termination. Although lithium based battery chemistries typically employ some method of charge termination to ensure consumer safety, other battery chemistries, such as nickel cadmium and nickel metal hydride, can employ much simpler charge control approaches that overcharge the batteries for long periods of time. Overcharging heats up the battery, reduces its lifetime, and consumes more energy than more sophisticated charge control approaches. Voltage comparator and other charge control circuits can be implemented to enable a much lower trickle current, or hysteresis charge can be employed to counteract self-discharge periodically.

Power scaling: reducing power draw when less functionality is required. Currently, some domestic BCSs that incorporate additional consumer functionality do not effectively reduce power draw when these functions are "turned off" by the user. One example is a BCS that incorporates answering machine capability for a cordless landline phone. No-battery and battery maintenance power can be reduced by ensuring the button used to power off the answering machine function also cuts off power to the relevant circuitry. This helps ensure that when consumers are not using the answering machine, they are also not "paying" for that function on their electric bill. Circuit design options for improving power scaling vary. Reducing "no load" power supply losses are well understood and widely employed.

Although energy savings opportunities exist to employ efficient battery chemistries, the MEPS in California do not require battery chemistry changes in order to comply. Costs of more efficient battery chemistries are falling, but many opportunities to increase efficiency exist even without total market shift to more efficient chemistries. The list of BCSs compliant with California MEPS features all domestic battery chemistries, including nickel, lithium, and lead-based chemistries [10]. California estimated a 7:1 benefit to cost ratio based on California electricity prices, making the improvements highlighted above very cost-effective to citizens of California [11].

Energy Savings Opportunities

Because battery chargers systems are incorporated into so many different end use products, the energy use and savings opportunities are extensive. Table 2 below represents our estimate of energy savings opportunity from the battery charger systems in power tools and lawn maintenance tools, phones and phone accessories, cameras, personal care appliances, laptops, auto/marine chargers, domestic uninterruptible power supplies, low-speed personal electric vehicles, and golf carts. Also, it includes non-consumer categories of emergency backup lighting for buildings, handheld barcode scanners, two-way radios, and forklifts. We derived these estimates by translating U.S. energy savings analyses for battery chargers to other regions based on a gross domestic product (GDP) weighting approach. This approach provides a first-order approximation of global energy savings potential if policy implemented is similar to MEPS implemented in California. In our experience, battery chargers are one of the largest untapped energy savings opportunities. There are multiple power plants worth of savings in several regions, including Europe, China, and Japan.

Table 2: Estimate of energy savings opportunities by territory/region

Territory or Region	Savings (TWh)
California [9]	2
North America	20
Europe	20
China	9
Australia/New Zealand	2
Brazil	3
Japan	7
South Korea	1

The California estimate was originally closer to 3 TWh, but the final standard was not quite as stringent and had some more exemptions. We scaled from California to other jurisdictions by GDP market exchange. Though purchasing power parity GDP is appropriate for local consumption with lower local wage rates, electronics tend to come from overseas, so the market exchange is more appropriate.

The only study we are aware of outside of the U.S. on battery charging systems is one done by BIOIS in Europe [12]. Though the authors state that battery chargers only consume a few percent of the total energy of battery chargers and EPSs, this is defining a battery charger as a system with no other purpose, e.g. charging AA batteries. If battery charger system is defined more broadly and all modes of operation are considered, the energy savings opportunity goes up considerably, and so we believe our estimates are consistent with this study.

U.S. Policy Overview

Test standard

In 2005 the U.S. Department of Energy (US DOE) was directed by the U.S. Congress to create aMEPS for battery chargers, including developing an official test standard. An initial test standard that only covered the low-power modes of battery chargers was last revised in the U.S. in 2009, and then amended in 2011 to include the active mode charging efficiency [13]. The final test standard relies heavily upon the California test procedure adopted in 2008 with some important improvements and amendments. This test standard focuses on domestic BCSs. California also has a test standard (and MEPS) for larger commercial and industrial systems [14].

Small and large BCSs differ in design and application, so the measurements and metrics of charge mode efficiency are different for each. For small BCSs, charge mode efficiency is defined over a 24-hour period. Power conversion efficiency (ac to dc) and charge return factor (amount of charge (Coulombs) into the battery divided by amount of charge out) determine the charge mode efficiency in large chargers. The power drawn in battery maintenance and no-battery modes is also an important factor for all types of chargers. Table 3 below provides a snapshot of these test procedure outputs and their respective ranges measured in the lab.

Table 3: Snapshot of Unregulated Battery Charger Performance Ranges

	Small Battery Chargers	**Large Battery Chargers**	
Active mode metrics	***24-hr System Efficiency***	***Charge Return Factor***	***Power Conversion Efficiency***
	2% - 71%	1.34 - 1.05	74% - 93%
Maintenance Power Range	0.12 W - 70 W	0.04 W - 290 W	
No-Battery Power Range	0.05 W - 70 W	0.04 W - 280 W	

In practice, 24-hour system efficiency can be replaced with 24-hour charge energy if the amount of charge energy allowed by the MEPS scales with the associated battery's energy capacity in watt-hours. An energy metric, instead of an efficiency metric may be a better conceptual approach in some cases, as the 24-hour energy can include additional low power functions that cannot be turned off by the consumer. We use 24-hour efficiency for this discussion as it enables us to easily compare efficiency ranges across the full range of battery capacity.

MEPS approaches

Although U.S. stakeholders achieved general agreement on test standards, the U.S. DOE and California take different approaches to regulating energy use of these systems (Table 4). California's authority to regulate not only domestic, but also commercial and industrial battery chargers gives the MEPS a more expansive scope than DOE's more limited authority focused on consumer products only. Also, DOE generally prefers to have one metric to use for regulation, and so combines the outputs of the test procedure with assumptions about representative product duty cycle to enable a single annual energy use metric. While annual energy use can be an effective approach to address the energy use of more homogeneous product groups, products that are powered by battery charger systems vary widely, even within one DOE product class. For example, both laptops and power tools are within DOE product class 4. Because not much data exist on the field operation of the more than 50 individual end uses that incorporate battery charger systems, California chose two metrics focused on low power modes (no battery mode and maintenance mode) and active mode. By focusing on modal power rather than annual energy use, California mitigated the risk that a product could meet the MEPS but not actually save energy in the field because its actual use could be vastly different from the duty cycle assumed for the representative product. This metric is more similar to the external power supply metric approach adopted world-wide.

Table 4: U.S. approaches to MEPS

	U.S. DOE	**California**
Scope	Domestic only (includes golf carts)	Domestic, commercial and industrial
Metric	Annual Energy Use (kWh)	24 hour charge energy, combined low power limit
Product classes/categories	10 categories defined by battery voltage and charger utility	4 categories defined by battery charger utility: operation in a wet environment, backup power, general, and large (>2 kW)
Approach to scale within each product class	TBD	Continuous function that changes as the battery energy capacity changes
Effective Date	TBD; range includes 2015 to 2018	February 1, 2013 domestic for general BCSs, inductive and USB chargers; January 1, 2017 for small non-consumer products; January 1, 2014 large BCS and USB BCS
Status	Ongoing, latest action was request for information from stakeholders given recent compliance requirement in California	Complete

Lastly, California divides battery charger systems into four product classes, whereas DOE has ten product classes. Ten product classes, each with a representative product, helps increase the possibility that the product and duty cycle chosen is more representative than it would be with fewer classes, but does make the MEPS framework more complex than California's four classes.

Standby and External Power Supply Policy Interaction

Although the U.S. and California do not have comprehensive MEPS for standby power, many regions of the world do. Also, some battery charger systems include an external power supply (EPS) as well, and questions of overlap in scope and modal definitions must be addressed to support a common understanding for policymakers and manufacturers alike. For example, no load power (EPS), no battery mode power (BCS), and off mode power could all apply to the same situation (e.g. a cell phone external power supply is plugged into an outlet but disconnected from the phone).

Table 5 summarizes EPS and standby policy for various regions of the world. Possible implications include:

- BCS MEPS may require lower no battery/maintenance power than current 0.5 and 1 W standby provisions in the EU, Korea, Australia, and other jurisdictions. This may affect certain small battery charging products like cell phones or consumer portable audio/video products.
- BCS MEPS may encourage the use of more efficient power supplies than currently required under MEPS in order to meet 24-hour efficiency targets. Although improvements in batteries and charge control circuitry are other technological pathways to achieve the same energy

performance, the EPS is often one of the less expensive pathways because of the maturity of the market and relative ease of this design change.

Overlap with EPS MEPS has been effectively addressed in U.S. and California. In California, manufacturers are required to meet both EPS and BCS MEPS for products that use both technologies. Although DOE has not finalized its rule, prior publically released documents indicate DOE will take a similar approach to the overlapping scope.

Table 5: Summary of International Policy

Jurisdiction	**Standby Policy**	**EPS Policy**
Australia & New Zealand	Expected 1 W in 2013	MEPS
EU	Eco-design 1 W standby directive	Eco-design directive
South Korea	1 W voluntary standby initiative	MEPS
China		MEPS
US		MEPS

Conclusion

Opportunities for other international jurisdictions to leverage California's cutting-edge MEPS when setting their own policies can support increased compliance and ease manufacturer burden, particularly for products like electronics that are often manufactured in Asia and shipped globally. Standby definitions and external power supply scope overlap would need to be carefully considered in each jurisdiction. The current world-wide opportunity to leverage U.S. and California test procedures and California MEPS for battery charging systems could save Europe alone as much as 20 TWh per year, which is roughly equivalent to the entire electricity use of Iceland.

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Potential for Energy Savings for Personal Video Recorders in Australia.

Keith Jones and Paul Ryan

Abstract

Personal Video Recorders (PVRs) continue to have increased popularity among consumers. They offer consumers recording, time slipping and replay of TV broadcasts as well as access to the internet to stream video and audio content from websites such as YouTube. Currently in Australia subscription television providers have STBs with recording capability and the energy consumption for these devices is covered under the Australian Conditional Access Set Top Box Code of Conduct (CSTB CoC), however, no programme exists for the free to air counterparts.

This paper reports the findings of a study conducted by Digital CEnergy Australia (DCA) that characterized the energy consumption of video recorders (VRs), assessed the market for VRs and the resulting energy consumption projected out to 2020. Modeling was conducted for low, medium and high market growth scenarios. In this paper only the medium modeling is reported in detail. The study also conducted measurements on 11 VRs available in the Australian market. The results of these measurements were used for the subsequent energy consumption modeling.

The result of the study showed that using similar limits as exist in the CSTB CoC that potential cumulative energy savings of up to 400GWh and cumulative carbon savings of around 340 kT by 2020. The report concludes that there is significant potential for energy savings through the implementation of a VR energy consumption programme.

Background

Since 2001 Australia has been in the process of converting its free-to-air (FTA) television broadcasting from analogue technology to digital technology. This has seen the replacement of traditional video cassette recorders (VCRs) with digital video recorders (DVRs). These devices are also known as Personal Video Recorders (PVRs) and simply VRs. VRs, PVRs and DVRs have storage devices in the form of hard disk drives (HDD) and optical disks (DVD[1] and Blu-ray[2]). In this report the term VR will be used to describe all types of digital video recorders. New forms of recorders have emerged that contain combinations of HDDs and Optical disks.

These digital devices have not only replaced the functionality of VCRs but have also spawned new uses of recording equipment such as time shifting of programmes and real time review and playback of the programmes being watched.

VRs have been in the market for several years but more recently VRs with removable optical media have also emerged. The removable media are in the form of Blu-ray disc (BD) and DVD generally referred to as optical disks. All types of VRs are showing very strong growth according to GfK retail sales data [1].

Product Coverage

Video recorders are the group of equipment which receive free to air digital TV broadcasts and can record these broadcasts. Video recorders include Removable Optical Disk recorders (DVD, BD). BD recorders operate in a similar manner to DVD recorders but have a higher memory capacity allowing them to record high definition programmes which can be played back on HD TVs. Solid state recorders have either fixed or removable solid state memory.

Video recording technology is expanding rapidly and has seen the optical disk/HDD become more widely available. Increasingly, the fixed media recording devices (with HDD) are penetrating the

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[1] DVD is a trademark of the DVD Format/Logo Licensing Corporation

[2] Blu-ray is a trademark of the Blu-ray Disc Association

Australian consumer market. The sale of VRs in Australia are estimated at 300,000 units per annum between 2007 and 2010 [1] and the population of VRs in Australia is estimated at around 1 Million units in 2010.

Nearly all VRs can receive and decode free to air digital TV high definition broadcasts.

Video Cassette Recorders, generally known as VCRs, are now largely obsolete.

Australian VR Market Growth

The forecasts in this paper are based on a number of assumptions and, like all forecasts, the end result will depend on how robust the assumptions are. For this study low, mid and high growth forecasts have been produced. They have been produced by considering the growth rate that is clear in the GfK data between 2009 and 2010. Another factor is the market saturation point, that is, how many homes are likely to buy an STB or VR. The last factor in the assumptions is the life of the product itself.

The actual growth of the VR market between 2009 and 2010 is shown in Table 1.

Table 1: Sales Growth of VRs between 2009 and 2010 (GfK 2009 – 2010)

Product Type	Growth
HDD VRs	+29.5%
Optical Disks Plus HDD VRs	+14.4%
Total VR Growth	+19.4%

VRs with HDD have a higher growth rate but VRs with optical disk drives and HDDs still have double digit growth. This is likely to be because VRs with a DVD or BD as well as a HDD are a newer product and the growth rate has not peaked yet. It is unlikely that these growth rates would continue in the long term because they will quickly saturate the market and growth will slow to the level determined by replacement of old units.

The study conducted by Digital CEnergy Australia used low, medium and high growth models, but in this paper only the medium growth model is presented. Table 2 shows the assumptions that have been made for the modeling.

Table 2: Assumptions for the medium market projections for VRs.

Assumption	Medium Model
Growth	2011-2012 - 25% 2013 – 2014 20% 2015 – 15% 2016 -2020 10% falling to 2% in 2020
VRs per House Hold	0.625
Usable Life	5 Years
Stock as at 2009	1M

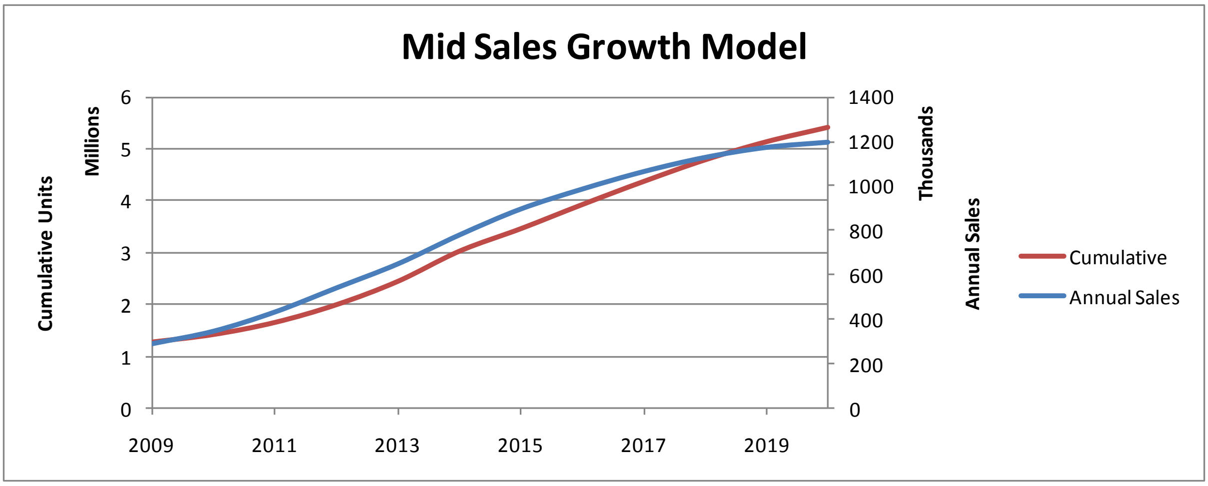
The growth rate is based on the actual growth between 2009 and 2010 and the level of growth that is likely between 2010 and 2020 to achieve a saturated market at the levels of VRs per household stated for each model.

The usable life has been based on experience with STBs over the last 10 years. The main failures are in the power supply and the HDD unit. Some replacement will also occur as consumers seek to update their units to newer technology such as IPTV and MPEG 4 capable STBs and VRs.

The stock levels are based on GfK data from 2003 – 2010.

Figure 1 shows the market trend for STBs and VRs based on GfK data up to 2010 and provides a forecast to 2020.

Figure 1: Mid Sales Growth Model for the VR market growth from 2009 with forecast from 2011-2020



This scenario has the market saturating at around 5 million units most of which will be purchased post 2012.

Energy Consumption Testing

Home electronics are estimated to be responsible for at least 5% of household energy consumption in Australia, making it larger than the combined energy consumption of clothes washers, dishwashers and dryers [2].

The International Energy Agency (IEA) [3] estimates that overall, home electronics and ICT products accounted for 15% of global residential energy consumption (700TWh/yr), and that energy use from these devices will increase threefold by 2030, and are likely to comprise the biggest end-use category in many countries before 2020. The video recorders considered here are a major part of this overall category.

Product Coverage

The video recorders tested include the following:

- Video Recorders that contain HDDs
- Video Recorders that contain DVD recorders and HDDs
- Video Recorders that contain BD recorders and HDDs.

All video recorders tested were manufactured outside Australia. The market is dominated by companies based in Japan, Korea and China with the manufacture taking place in a diverse range of countries, mainly throughout Asia.

Description of Video Recorders Tested

Nine units were tested, all of which had hard drives. The HDD capacity varied from 160 GB to 1 TB. This information is summarized in Table 3.

Table 3: Video Recorders.

Model	Make	Type	HDD Capacity	DVD or BD	Number of Tuners
HHR787	Healing	DVR	500GB	N/A	2
SRT5495A	Strong	DVR	500GB	N/A	2
HDR2700T	TEAC	DVR	500GB	N/A	2
DMR-PWT500GL	Panasonic	DVR	320GB	Both	2
BD-8900A	Samsung	BD-HDD Combo	1 TB	Both	2
RDR-HDC300	Sony	DVD-HDD Combo	320GB	DVD	1
RH397D	LG	DVD-HDD Combo	160GB	DVD	1
HR698D	LG	BD-HDD Combo	250GB	Both	2
HDR-7500T	HUMAX	DVR	1 TB	N/A	2

A mix of brands was selected to ensure a good selection of well-known and lesser-known brands was tested. The selection included a mix of BD and DVD combination units as they are becoming popular choices of recording devices. Finally video recorders with only HDD recording were also included as they also represent popular consumer choices for both recording and displaying DTV broadcasts on an analogue television. All the VRs tested were capable of decoding high definition (HD) television signals.

Standards available for Video Recorder Power Consumption Testing

The only Australian Standard identified for testing video recorder power consumption was AS/NZS 62087.1:2010. This standard is based on IEC 62087 Ed 2. The section of AS/NZS 62087 that covers video recorders was found to be more concerned with VCRs and had not been updated for over 10 years. Therefore the standard was inadequate to cover the range of measurements that needed to be made with current VRs.

IEC 62087 Ed 3:2011 was studied as it contained an update to the power measurement of STBs that covered STBs with HDDs which is one of the categories of product covered by this document.

This study identified that with little modification all the operating modes of the VRs were covered in the STB section of IEC 62087 Ed3 with the exception of recording and playing optical discs. Using IEC 62087 Ed3 as the basic measuring standard and adding measurements for the optical disk operation produced an acceptable test method. Appendix A contains the measuring method used for the testing. The IEC TC 100 committee is currently revising IEC 62087 to update the video recorder section. The committee raft for this work is currently being circulated and is strongly based on the STB method of power measurement in IEC 62087 Ed3. For these reasons the IEC 62087 Ed3 was selected as the test method for STBs and VRs with the proposed Ed 4 requirements for VRs with removable Optical Media.

Power Modes

Table 4 shows the power modes for VRs and STBs from IEC 62087 Ed3. To make some of the terminology clearer for the testing in this report some of the modes have been clarified. This is shown in the third column of Table 4. Most of the clarification is concerned with examples of VR activity in the respective power modes.

Table 4: VR Power modes

Mode	**Video recording equipment**	
(e.g. VCR)	Comment	
Disconnected	The appliance is disconnected from all external power sources	
Off	The appliance is connected to a power source, does not perform any mechanical function (e.g. playing, recording) and cannot be switched into any other mode with the remote control unit, an external or internal signal	
Standby-passive	The appliance is connected to a power source, does not perform any mechanical function (e.g. playing, recording), does not produce video or audio output signals but can be switched into another mode with the remote control unit or an internal signal	This is the most common form of standby for STBs and VRs. This mode covers VRs that have been programmed to record a future programme and are waiting for a timer to signal that the recording is due and turn on the VR to record
Standby- active, low	Standby-passive and can additionally be switched into another mode with an external signal	This is not a common mode for terrestrial FTA VRs
Standby-active, high	Standby-active, low and is exchanging/ receiving data with/from an external source	This would cover downloading Electronic Programme Guides
On (Play)	The appliance is connected to a power source and plays the disc inside the appliance or a pre-recorded programme	
On (Broadcast)	The appliance is performing the function of providing a viewer with video and audio from a broadcast	
On (Record)	The appliance is connected to a power source and records a signal from an external or internal source	This could include copying HDD programmes to a DVD or BD.
On (Multifunction)	The appliance is performing multiple functions simultaneously	For example recording one programme at the same time as playing a previously recorded programme

Test Process

Testing for STBs and VRs was done according to IEC 62087 Ed3:2011 Section 8. This is the latest international standard for STB testing. For the VRs this included the testing for multiple tuner operation including multiple recording and playback.

Test Results and Analysis

Video Recorder Standby Test Results

The standby results for video recorders are shown in Table 5.

Table 5: Video Recorder Standby Test Results

Model	Type	Standby Power (W)	Standby Power Factor (PF)	Standby (Recording Programme)	Standby (Recording Programme) PF
HHR787	DVR	0.64	0.17	0.6	0.17
SRT5495A	DVR	0.66	0.22	0.6	0.22
HDR2700T	DVR	0.70	0.17	12.2	0.49
HDR-7500T	DVR	0.83	0.14	0.8	0.14
DMR-PWT500GL	BD-HDD Combo	1.12	0.28	1.1	0.28
BD-8900A	BD-HDD Combo	1.48	0.25	1.5	0.25
RDR-HDC300	DVD-HDD Combo	3.37	0.39	3.4	0.39
RH397D	DVD-HDD Combo	2.78	0.35	2.8	0.35
HR698D	BD-HDD Combo	0.78	0.19	0.8	0.16

These results show that except for the HR698D the VRs with BD or DVD disks performed worse for standby than the VRs that only had a HDD. The passive standby mode was activated by programming a recording 2 hours into the future and then turning the VR into standby. As is evident from the results three of the four VRs with only HDD had an active standby similar to the passive standby whereas the model HDR2700 was considerably higher at 12.1W.

The VRs with optical disks all had similar active standby power consumption as their passive standby consumption. This would suggest that all VRs except the HDR2700T have a low power wake up processor that stores the time for the recording and will switch the recorder on at that time to record the programme. As is shown in the next section the active standby for the HDR2700T is only 0.6W lower than the On mode. This would indicate that in active standby this VR is only muting audio and blanking video.

On Mode Test Results

Table 6 and Table 7 show the On mode results for the STBs and VRs tested. For this test the On (Broadcast) mode was used. The output was connected to the display via HDMI cable. The results show that for On (Broadcast) the STBs were well within the allowable On (Broadcast) for STBs as specified in AS/NZS 62087.2.1. Both these STBs are High Definition and given the passive standby mode results for them, they would have a base allowance of 15 Watts.

Table 6: Video Recorder On(Broadcast) Test Results

Model	Type	On	PF
HHR787	DVR-HDD Only	12.0	0.54
SRT5495A	DVR-HDD Only	20.3	0.57
HDR2700T	DVR-HDD Only	12.8	0.50
HDR-7500T	DVR-HDD Only	19.8	0.53
DMR-PWT500GL	BD-HDD Combo	20.5	0.56
BD-8900A	BD-HDD Combo	24.8	0.59
RDR-HDC300	DVD-HDD Combo	18.8	0.57
RH397D	DVD-HDD Combo	22.4	0.54
HR698D	BD-HDD Combo	20.1	0.58

Figure 2: The spread of On (Broadcast) Power consumption for the categories of VRs.

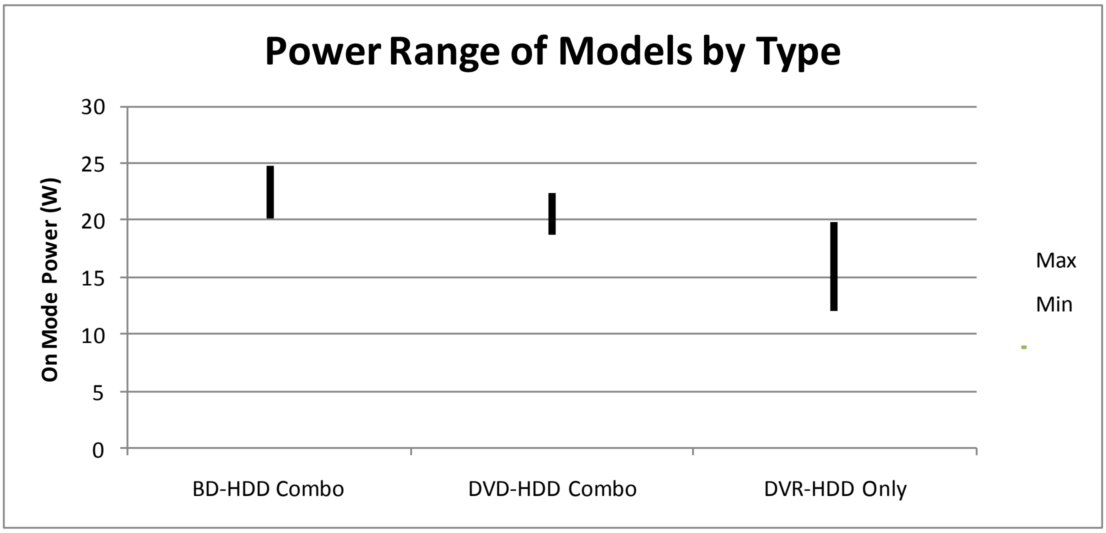


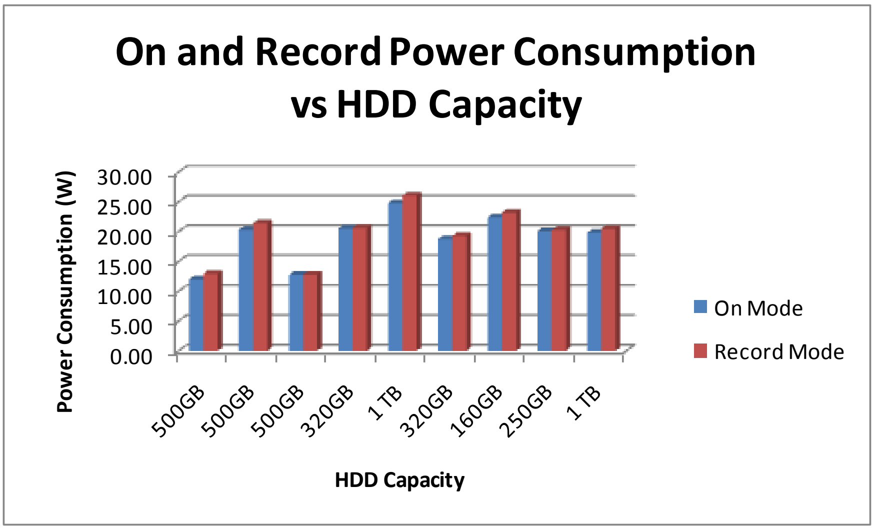
Figure 2 shows graphically the spread of power consumption for the three categories of VR. What is clear is the VRs with optical discs are consuming somewhat more power than VRs that do not have optical discs. It is also clear that VRs without optical drives have a larger spread of power consumption than VRs with optical drives. The reason for this is unclear as the optical drives are not being operated in this mode. One explanation for the power difference between the units could be whether the HDD is spinning regardless of any recording activity. However, other studies have concluded that the power consumption of a spinning disk drive should be less than 5W.

It also seems that DVD combo types consume a little less power than BD combo types.

Comparison of power consumption verses HDD Capacity

Figure 3 shows the power consumption for On (Play) and On (Record) by HDD Capacity.

Figure 3: On (Record) and On (Play) power consumption verses HDD Capacity



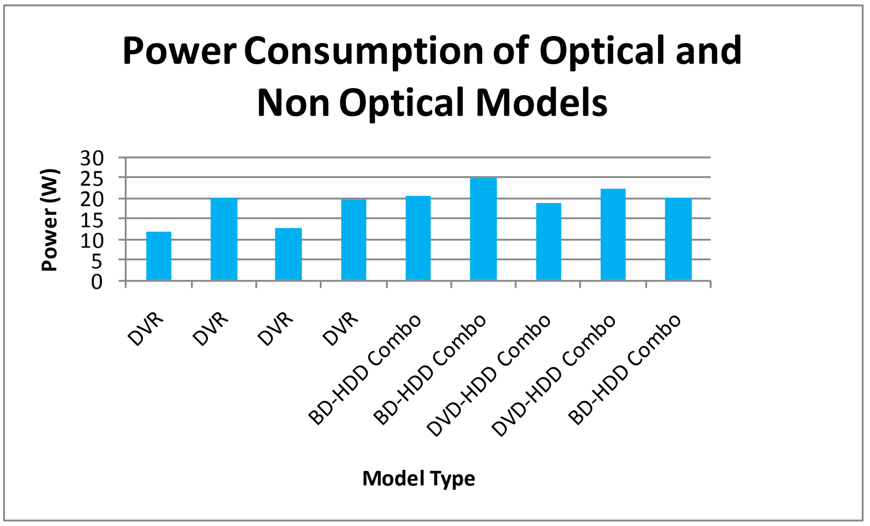
The chart does not show any significant trend between the disk size and the associated power consumption. The highest power consumption is for one of the 1 TB HDDs but the other 1 TB HDD is consuming less power than the 160 GB drive and the lowest power consumption is actually being achieved with a 500GB HDD. The second highest power consumption is from the 160 GB drive.

This means that it will not be wise to try and separate product into categories based on HDD capacity.

Comparison of power consumption for VRs with and without Optical Disc Drives

Figure 4 shows the power consumption of VRs with and without optical disk drives. Although the models with an optical disc drive exhibit on average higher power consumption some are actually below some of the models that do not have an optical disc drive. It may be also hard to categorize VRs on the basis of whether they have an optical disk drive. An alternative scheme is presented in the conclusions section.

Figure 4: Comparison of power consumption for VRs with only a HDD and those with an Optical Disc Drive.



STB and VR Energy Use Modeling

Proposed Energy Use Profile

Australian Code of Conduct for CSTB

The Australian Voluntary Code for CSTBs is based on the European Union voluntary code. It contains functional adders that can form the basis for the allowances applicable to VRs for such features as recording. The CSTB Voluntary Code can be applied to determine the typical (annual) energy consumption (TEC) limits for the range of products from STBs to VR with and without removable optical media.

Allowances used for Business as Usual (BAU) Modeling.

Table 7 shows the allowances used for the BAU Modeling.

Table 7: Allowances used for BAU modeling.

Allowance Type	**Allowance Level kWh/Year**
Base Allowance	15
Additional Tuners	7
Adv. Video Processing	0
DVR	8
Home Network Interface	18
High Definition	0

The allowances have been calculated based on the measurements of the VRs tested and available information on how much power the features are likely to require. They are also predicated on automatic power down (APD) being a requirement for any implemented programme which means that the On mode time per day is restricted to 4.5 hours if no one is watching the STB services.

An allowance for an optical disc drive has not been provided as it is not clear what this allowance should be. As can be seen from the reported measurements for a number of DVD/BD recorders, there was no difference in the power consumption whether the DVD/BD disk was playing or not. Also it is clear from the Top Runner program in Japan that average DVD/BD disc use is only about one hour per day so the contribution to energy use is actually very small. A determination on this allowance can be made at a future time.

General

This BAU modeling has used the allowances as explained in the previous section and the market data provided in this paper. The medium growth scenario has been modeled for VRs based on a regulatory framework from late 2014 which is the earliest practical year any regulation could be developed and implemented.

Table 8 shows the conversion factors to derive the CO_2 emissions for each year. These are the same as those used for the CSTB BAU modeling. As the CSTB CoC is the only other programme in Australia that covers STBs with recording capability it seems useful to use the same conversion figures.

The TEC for each unit tested has been calculated and then the average for the VRs has been used to calculate the energy use. The VRs have not been split into those with and without optical disk drives because the relative proportion of the population in 2010 for each type cannot be readily determined. The average of all VRs is a reasonable representation of the overall energy use.

Table 8: Energy use to CO_2 conversion factors for each year.

Year	**kg/kWh**
2009	0.99
2010	0.98
2011	0.96
2012	0.95
2013	0.93
2014	0.92
2015	0.90
2016	0.88
2017	0.86
2018	0.85
2019	0.83

BAU for the Medium Growth Scenario

Table 9: CO_2 emissions for the Mid Growth Scenario. shows the energy use for the medium growth scenario. For this scenario the energy use stabilizes after the MEPS becomes effect effective in 2015. This is due to older less efficient STBs being replaced after 2015 and the population of STBs still increasing with greater market penetration. If a second tier of MEPS was introduced in 2018 then there would be additional savings expected beyond 2018.

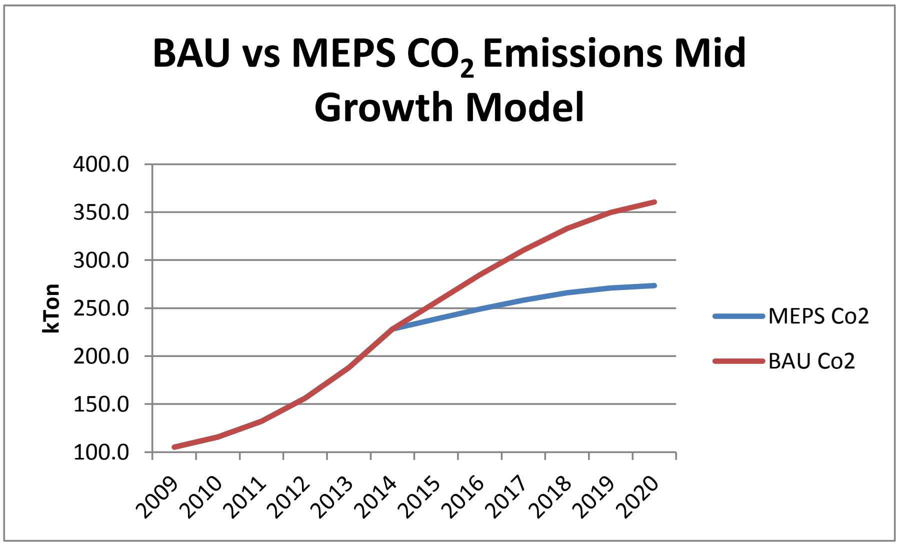
By 2020 the cumulative energy savings would be 400 GWh. At a minimum project cost of 29 cents/kWh this would total around $117 million.

Table 9: CO_2 emissions for the Mid Growth Scenario.

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
MEPS GWh	106.0	117.9	137.0	164.9	201.7	249.1	265.1	282.2	298.6	313.9	326.8	337.0
BAU GWh	106.0	117.9	137.0	164.9	201.7	249.1	284.6	322.6	359.0	393.0	421.7	444.4
MEPS CO2 kt	105.3	115.5	132.0	156.3	188.0	228.3	238.7	249.1	258.2	265.9	270.9	273.4
BAU CO2 kt	105.3	115.5	132.0	156.3	188.0	228.3	256.3	284.7	310.5	332.9	349.6	360.5

Table 9 shows the CO2 savings to 2020. The cumulative savings of CO2 are 338 kT from 2009-2020.

Figure 5: BAU vs. Proposed MEPS Limits for CO_2 emissions – Mid Growth Model.



Conclusions

VR Market

The VR market is growing significantly and is expected to continue well into the future as consumers see benefit in the recording features that they offer. High in importance is the ability to time shift programmes so that they can be viewed at a more suitable time than when they were broadcast. The recorders also offer the ability to series record so that no episode of a series is missed. This also allows the viewer to watch the series again. VRs with optical disk also offer the ability to move recordings to DVD or BD disks for archiving. The combination of these benefits would indicate that the market for VRs is strong and will get stronger.

It is expected that by 2020 the VR market will be between 800,000 and 1,400,000 units annually and the stock allowing for replacement will be 4 and 6 Million. The stock as at 2012 is around 2 Million so between 2 and 4 Million units will be added before 2020.

DTV STB Market

The demand for STBs was fundamentally tied to the switchover from analogue to digital TV. This process is nearing completion and all TVs now sold in Australia have digital tuners. The STB market therefore has now begun a sharp decline and will become a market for FTA satellite services by 2020. By 2020 there will be less than 100,000 units sold annually and the stock will have declined to around 800,000.

IPTV STB Market

It is difficult to estimate this market as it is very embryonic. It is clear, however, that it is likely to grow quite significantly. With 8 million households in Australia, even if penetration is at the level of subscription television, it is likely that the market will be at least 3 million by 2020.

Power Test Results

The following conclusions have been drawn from the discussion of the power testing results:

- It is difficult to categorise VRs based on their functional attributes such as optical drives or HDD capacity.
- A VR is basically an STB with additional recording functions so the Australian Conditional Access STB Code of Conduct can be used as a basis for MEPS.

There is scope for better power management with regard to tuners and HDD operation.

The basic element of a VR is a tuner and decoder chip set. This is functionally the same as used for an STB. What distinguishes a VR from an STB is the additional tuners and recording mechanism that allow the recording and/or playback of multiple programmes. In the case of VRs that have optical drives, the distinguishing features are the optical drive and the additional components that make that drive functional. Nearly all VRs have at least an HDD. As will be seen in Part 2 of this profile there is little market evidence of VRs that only contain an optical disk drive.

Rather than trying to categorize VRs by the HDD capacity or the type of recorder in them, it is proposed that the same approach be taken as for the Australian Conditional Access STB Code of Conduct or the European Voluntary Agreement for STBs which provide a base level for a receiver (STB) and then applies adders to make allowances for the increased functionality for the various forms of VRs. It is also recommended that this approach be a TEC approach

Given the power consumption measurements for the STBs it is also clear that the base and additional allowances for free to air terrestrial based VRs in the Australian Conditional Access STB Code of Conduct needs to be reviewed.

Table 10 shows a summary of the savings for all three growth scenarios modeled in the DCA report. Clearly even for the low growth case there are significant savings to be obtained. For the high growth scenario the case for MEPS is even more compelling.

Table 10: Summary of Cumulative Savings for VRs to 2020 for the Three Growth Scenarios

Growth Scenario	**Energy Saving**	**CO2 Saving**	**Cost saving @ 29c/kWh**
Low	218.6 GWh	184.4 kt	$63.4 M
Mid	401.7 GWh	338.3 kt	$117 M
High	457.1 GWh	384.4 kt	$133.3 M

It is also clear that given the declining market for terrestrial broadcast STBs that there may be little to gain in more stringent MEPS levels. However, this needs to be considered in the light of new types of STBs emerging such as IPTVs and STBs that can decode MPEG 4 or receive DVB T2 transmissions which can be used with TVs that lack these features to receive these services when they are offered in the future. For this reason there may still be good reason to include STBs and ensure that any new emerging technology STBs have appropriate MEPS levels.

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Behave and save money in consumer electronics products

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Abstract

The household demand for consumer electronics products is rapidly increasing. Householders' behaviour is changing and is becoming more energy intensive, since they are spending additional time in several entertainment activities. This trend is causing an increase in the overall energy consumption, partially due to the products' standby and off-mode consumption. In addition, the lack of householders' awareness and sometimes unwillingness to change behaviours in order to eliminate standby and off-mode consumption is concerning as well.

One of the most effective approaches to raise householders' awareness to these issues and persuade them into behavioural changes is to give them specific recommendations and especially to demonstrate the impact of those recommendations on their electricity bill.

A study involving one thousand volunteer households in Portugal, between 2009 and 2011, highlighted that almost 60% of the households' electricity savings potential is related to entertainment and computing & telecommunication equipment. Within this category television sets (mainly CRT), in particular, DVD players and set-top boxes are the most widely used equipment in households, followed by HiFi systems and modems & routers.

The measurements and surveys carried out indicated that the participating families could save almost 2.6% of the annual average household electricity consumption by switching off the multiple sockets and shutting down or unplugging the consumer electronics equipment, but the remaining electricity savings potential is still 4.4%, equivalent to 30 €/year and corresponding to 41 kg CO_2/year, per household. The correct use of set-top boxes and television sets alone are responsible for 50% of this savings potential.

Background

The increasing energy demand observed over the years in the residential sector can be explained by more penetration of traditional home appliances and new electronic devices as a consequence of higher purchasing power. However, the responsibility for the rising of energy consumption must be shared with the dissemination of consumer electronics and with their design and marketing [1], since a major number these appliances are designed to be left in standby to facilitate updates [2].

The European Union (EU) has adopted several schemes and programmes to decrease the use of energy by consumer electronics. One is the ENERGY STAR, a two-decade voluntary programme started in the United States of America (USA) by the Environmental Protection Agency (EPA) and introduced in the EU in 2001, for office equipment only. This programme distinguishes, through a voluntary label that consumers can easily recognize, the products that comply with the energy efficiency standards [3]. The other is through the Ecodesign scheme, which specifies and restricts the maximum power consumption for standby and off-mode of electrical and electronic household and office equipment (Commission Regulation (EC) No. 1275/2008). This regulation states that the majority of consumer electronics present standby and off-mode losses, which were estimated to be 47 TWh in 2005 and could rise to 49 TWh in 2020, if no specific measures were taken [4]. In 2013 targeted regulation regarding various entertainment appliances and office equipment will be under discussion in the EU. Television sets were the first consumer electronics product to have an energy label, helping consumers to choose more energy efficient equipment.

In Portugal several studies have been undertaken to quantify the standby and off-mode losses of consumer electronics products. According to the REMODECE study, 14% of household electricity consumption in Portugal is spent in consumer electronics. Householders leave 85% of office equipment, like scanners, printers and copiers and 80% of entertainment equipment such as external hard drive and game console on off-mode when are not using the devices. Televisions sets and VHS recorders and cable/satellite set-top boxes stay in standby 50% and 43% of the cases, respectively, while for some office equipment (desktops, monitors and laptops) the rate is lower, 17% [5].

The SELINA project concluded that in 18.5% of the appliances measured in shops, the off-mode did not comply with the EU regulation limit for 2010 and if compared to the 2013 threshold the rate would rise to 41.5%. For the standby mode, 31% of the measured products did not observe the EU regulation limit and if compared to the 2013 threshold the figure would increase to 66.4%. Particularly for Portugal, another conclusion from this European study, revealed that the retailers' advice priorities and the shops information about energy consumption are insufficient and do not favour the consumers' choice [6].

Statistics data available for Portugal from periodic surveys, confirm the increase of consumer electronics products penetration rate in Portuguese households since 1995 (Figure 1) [7][8]. The last survey indicates that, per household, the average number of television sets is 2.0, 1.4 computers and 1.0 radio, HiFi system, printer and multifunction printer. Regarding the appliances electricity losses, the survey concludes that TV set is the appliance Portuguese households mostly leave on standby mode when not being in use, with 43.8%, followed by DVD player, HiFi system and radio which range from 21.5 to 17.8%. For the office equipment analysed, the multifunction printer has the highest share with 16.7%, the computer 10.4% and the printer 6.5% [9].

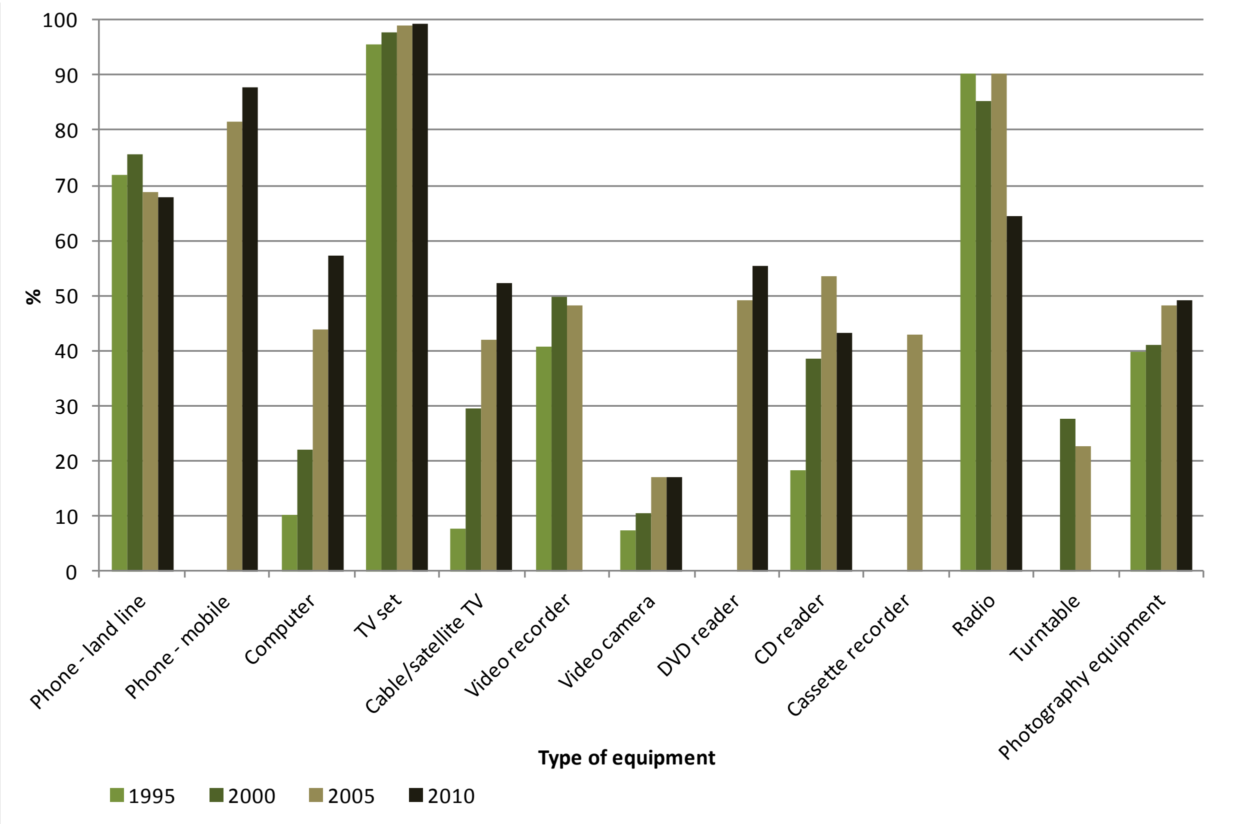

Figure 1 – Consumer electronic products penetration rate in Portuguese households [7][8]

Case study

The previous studies recognize not only the enormous energy savings potential by standby and off-mode elimination, but also that behaviour changes, like switching off electronic appliances is one of the most effective ways to achieve this goal [6][10].

The Ecofamilies II project was developed by Quercus, a leading Portuguese environmental non-governmental organisation, and promoted by EDP Distribution under Consumption Efficiency Promotion Plan (PPEC) 2009-2010 monitored by the Energy Services Regulatory Authority (ERSE). Among other areas, the project aimed at reducing electricity waste in standby/off-mode consumptions of consumer electronics equipment and raising citizens' awareness to questions related to energy savings in their daily lives. The closer and contextualised contact with the families in their households enabled to show them how behavioural changes could reduce their energy consumption without interfering in their quality of life and also to highlight the correct behaviours already implemented. The fact that only voluntary families participated in the project was relevant since people who already have a positive environmental attitude tend to put into practice energy saving advices and behaviours more easily. Also the feedback that families received after the visit in the form of a short report with targeted energy saving tips encourages an active participation in the household energy management fulfilling the projects goals [11][12].

The project's target group was not limited to the participant families but also to the general community as to multiply its effect. Eleven short monthly TV shows, broadcast in national television, were produced in collaboration with the participating families to illustrate how the energy savings potential could be achieved. One of which was specifically dedicated to how to eliminate standby and off-mode consumptions in consumer electronics. Short radio shows, seminars, conferences and workshops were also undertaken to the general public and schools.

Methodology

The project involved 1200 families whose registration was free of charge and voluntary as to engage more predisposed families to behavioural changes. All mainland districts were covered but most families lived in major urban centres near the coast line (72%). A thousand families were visited by trained technicians, but only data collected for 968 was considered valid. The overall participants, considering the family members, were 3017.

The evaluation of electricity savings potential due to standby/off-mode elimination of consumer electronics equipments was performed using a questionnaire and measurements with an energy data logger (Voltcraft Plus Energy Check 3000). In the questionnaires, the type and number of appliances, standby/off-mode consumptions and their usage habits by the family was registered. They were asked in which mode the equipments were left, when they were not being used, and for how long. During the visit, the family received a recommendation document regarding appliances energy usage and a multi-plug extension board with power switch to help them reduce the electricity consumption of standby/off-mode. The technicians involved the families in the assessment and demonstrated the correct behaviour for each appliance, enhanced the good practices already taken by the family and clarified their doubts. Only consumer electronic equipments on site were registered and measured.

The data collected was analysed to determine the savings potential in electricity, financial and environmental costs, in terms of CO_2 emissions by behaviour change and the results were communicated to the families in a report along with specific and targeted recommendations on how to avoid specific energy consumption. The report also underlined and quantified, whenever possible, the positive behaviours and energy savings achievements already obtained by the family as a way to encourage the new recommended measures and the maintenance of the implement ones.

Results

The project confirmed the increase in electricity consumption over the years and also the range and amount of home appliances in households, especially the consumer electronics equipments, when compared to a previous study developed by Quercus [13]. Each household spends on average 4002 kWh/year in electricity and 59% of the electricity savings potential is due to the entertainment (45%) and computing and telecommunication appliances (14%). Devices like TV sets, DVD readers and set-top boxes are nowadays practically compulsory in every household whose penetration rate is 2.2, 0.85 and 0.83, respectively (Figure 2).

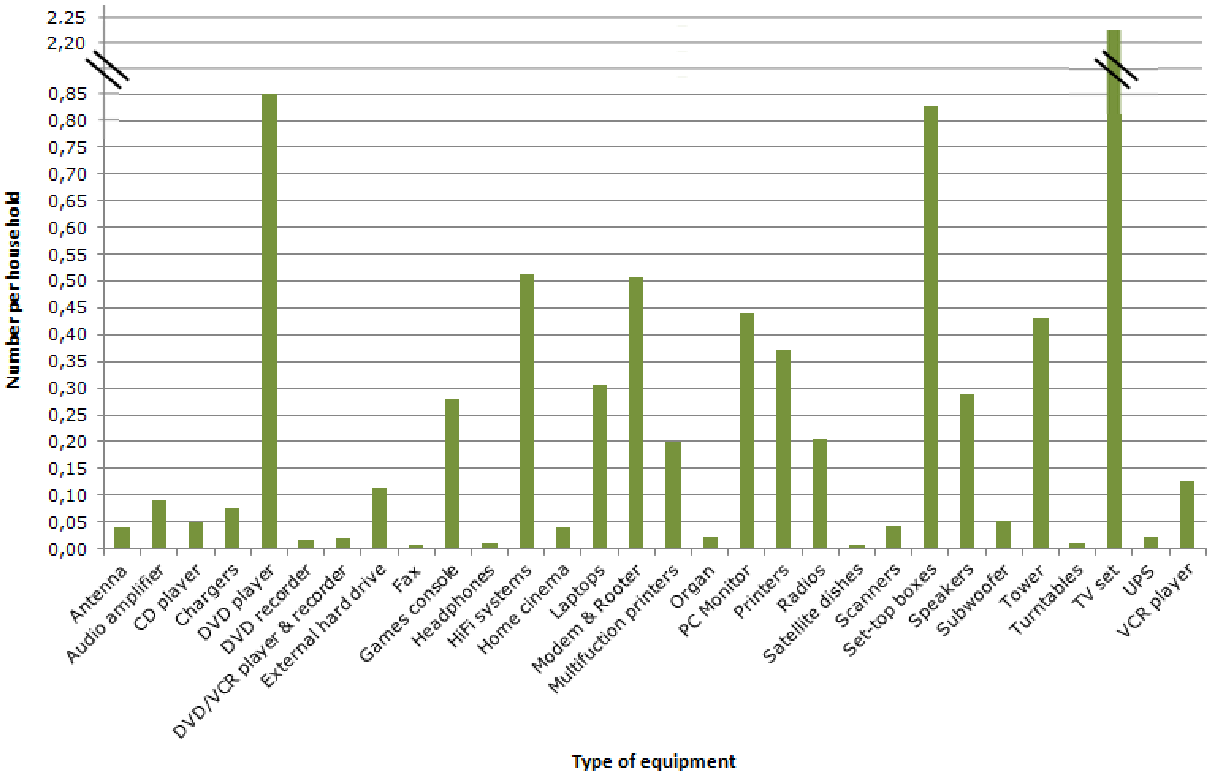

Figure 2 - Average number of consumer electronics equipments per household

The measurements and questionnaires made during the 2-years project indicate that typically this type of equipment has standby and/or off-mode consumption and is generally left in one of these modes when not being used. As shown in Figure 3, standby consumption was found mainly in entertainment equipment (43%) while off-mode consumption was more prevalent in computing & telecommunication devices (39%).

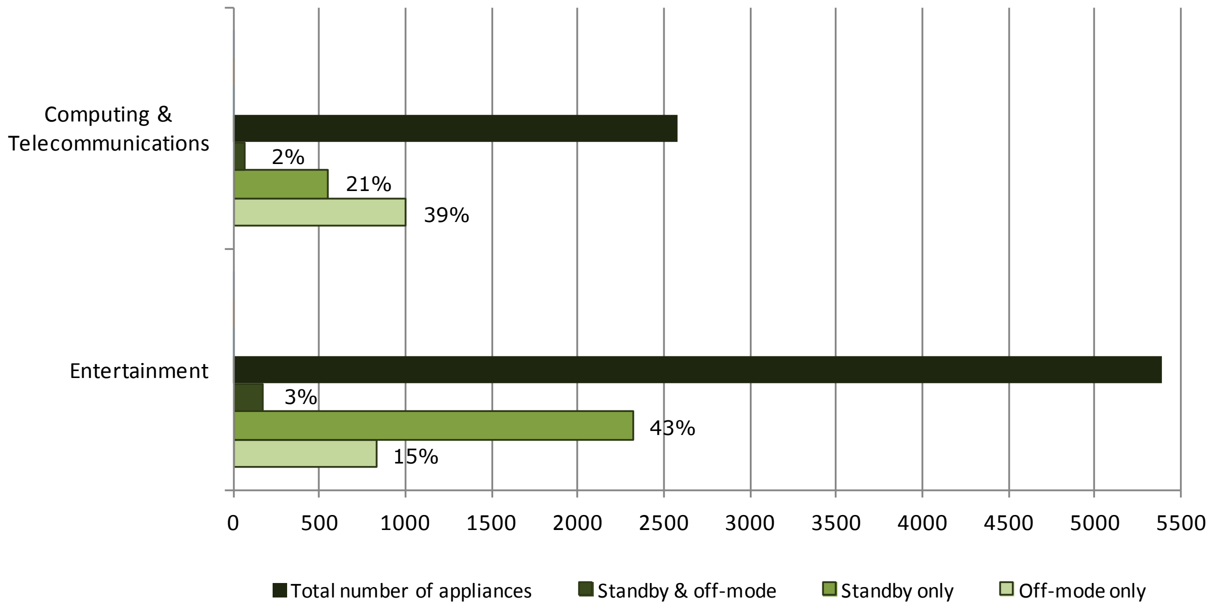

Figure 3 – Rate of consumer electronics equipments with standby and/or off-mode consumption

Most entertainment appliances with standby or off-mode losses are not connected to multiple sockets (62%) and for those that are (38%) only one third (12%) is actually switched off by the householder (Figure 4). On the other hand, the majority of computing and telecommunications equipment is connected to multiple sockets (53%) but the use given is nearly the same as the entertainment devices (14%).

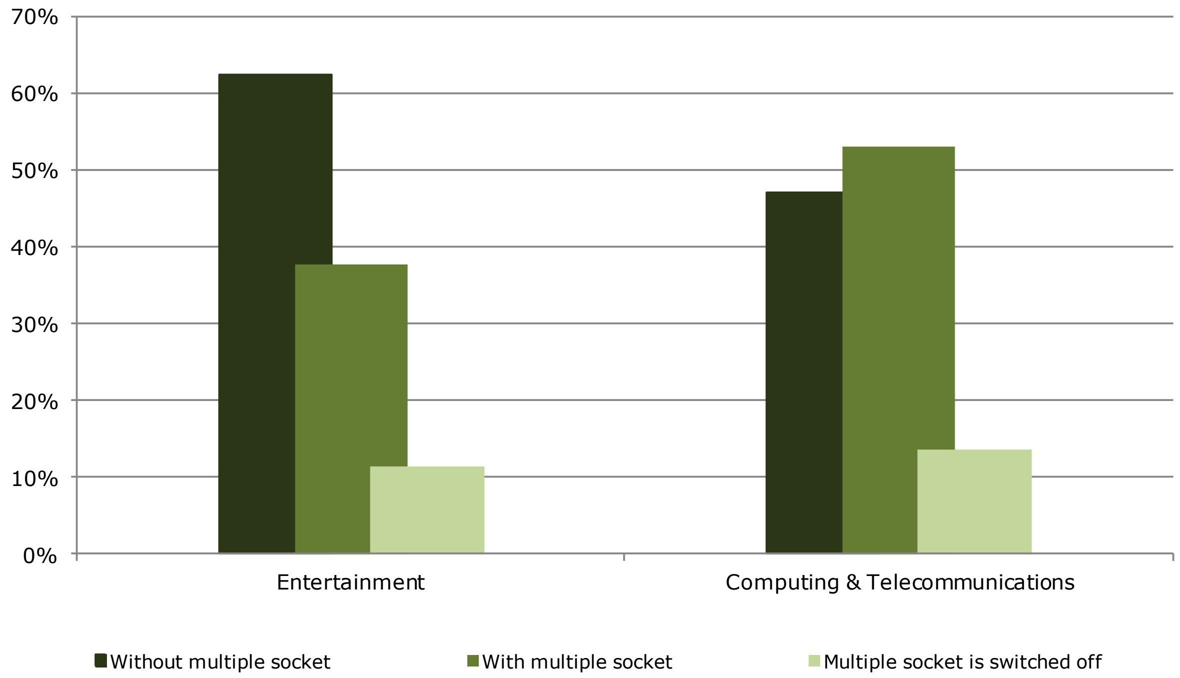

Figure 4 – Percentage of households with and without multiple socket and switch off behaviour

In order to encourage the good behaviours already put into practice by the householders and stimulate the implementation of new ones, the financial and environmental quantification of the former behaviours was computed, whenever possible to measure the electricity savings from switching off the multiple sockets, shutting down or unplugging the consumer electronics equipments. These actions account for 2.6% of the annual average household electricity consumption. The entertainment equipment is responsible for 76% of the electricity savings while the computing and communication devices are responsible for 24%. The standby and off-mode losses already cancelled by all participating households are equivalent to 101 MWh/year, corresponding to 17,270 €/year and to 23.2 tCO_2/year.

The remaining electricity savings potential is still 4.4% of the annual average household electricity consumption which represents 172 MWh/year, corresponding to 29,430 €/year and to 39.5 tCO_2/year. Per household is possible to save 177.5 kWh/year, equivalent to 30.4 €/year and correspondent to 40.8 kg CO_2/year.

As seen in Figure 5, set-top boxes and television sets are responsible for more than 50% of this electricity savings, both in the potential and already achieved savings. The top three products in the two graphs belong to the entertainment category.

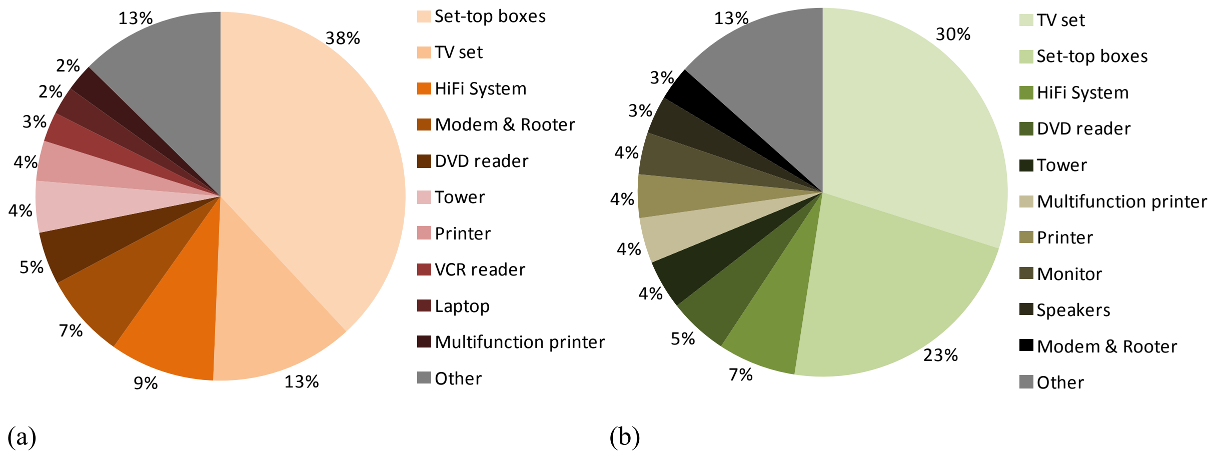

Figure 5 – Weight of major consumer electronics devices in the electricity savings potential (a) and electricity savings already achieved (b) of households

The case of television sets, in short

Since television sets, whose technology has changed recently from CRT, to plasma, to LCD and more recently to LCD-LED, have seen their electricity consumption reduced (on-mode, standby and off-mode) but their size increased, a more detailed analysis was performed.

The majority of the nearly 2150 TV sets registered is still CRT (51%), followed by LCD (35% of which 2% LED) and last the plasma (4%). In 10% of the cases the type was not available. Householders on average watch television for 2h48m, plasma viewers state that they spend more time watching television (3h22m) than the LCD viewers (12 minutes less), and CRT's (50 minutes less).

The off-mode consumption of these three technologies is nearly the same, around 0.2 Wh (the CRT is the lowest) but the standby consumption of CRT (5.8 Wh) is almost three times the LCD's and around twice the plasma's average standby consumption. However, the multi-plug extension boards with power switch are mainly connected to LCD and plasma television sets (about 43% for each type) and used especially associated with LCDs. Nevertheless more than 61% of the electricity savings is already obtained by the households and the remaining savings potential (39%) can be accomplished by switching off the television set or installing and/or using a power switch plug, in particular for the CRT.

Conclusions

The Ecofamilies II project surveyed one thousand volunteer households and is the most comprehensive assessment of energy savings potential in Portugal whose results were widely spread in order to induce a multiplier effect. Among other things, the project aimed at reducing electricity waste in standby/off-mode consumption of consumer electronics equipment and raising citizens' awareness to questions related to energy savings in their daily lives. The households received recommendations during the visits and afterwards they received a specific report with target recommendations highlighting financial and environmental implications along with the quantification of the good behaviours already implemented. The difficulty in accessing the plugs of some appliances and the householders' habits were some of the project's limitations which could have lead to underestimated electricity savings.

The entertainment devices are mainly left in standby, which is probably related to the updates sometimes these appliances automatically make and most of the computing equipment are left on off-mode, perhaps because households are not aware that these devices are still consuming energy when switched off.

The set-top boxes and television sets (mainly CRT) are responsible for more than 50% of this electricity savings, both potential and already achieved one. This technology of TV sets is also the one that contributes the most for the electricity savings potential.

Behavioural change is already taking place and the standby and off-mode losses cancelled by all participating households are equivalent to 101 MWh/year, corresponding to 17,270 €/year and to 23.2 tCO_2/year. The remaining electricity savings potential is 4.4% of the annual average household electricity consumption which represents 172 MWh/year, corresponding to 29,430 €/year and to 40 tCO_2/year. Per household is possible to save 178 kWh/year, equivalent to 30 €/year and correspondent to 41 kg CO_2/year.

However it would be interesting and important, for this kind of project, to observe the implementation of the recommended measures and assess its effectiveness in the long-term period.

Consumers' education through specific programmes and information dissemination is essential to induce the behavioural change and to push energy savings to the higher limit.

Acknowledgement

The Ecofamilies II project was developed by Quercus, promoted by EDP Distribution under PPEC (Consumption Efficiency Promotion Plan) and monitored by ERSE (Energy Services Regulatory Authority).

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Energy efficient broadband infrastructure in mobile and fixed networks and use in the domestic sector

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Abstract

The ever-growing number of Internet users, the introduction of new bandwidth-hungry applications and services as well as the vision of the Internet of Things[1] will set very high requirements on future access networks. Already today there are many different coexisting network technologies and protocols in the access area that have been developed and introduced to fulfill different needs of Internet users and heterogeneous applications. The growing complexity and increasing energy consumption of access networks raise a need for a comprehensive and effective modeling framework that enables a fast projection of energy efficiency of different access network infrastructures. This paper presents a comprehensive framework that joins technological parameters and various configuration options with socio-demographic characteristics and varying user behavior. The modeling framework can be used to evaluate different deployment and migration scenarios for both wireless and wired access networks by means of predicted energy efficiency. Taking into account possible further developments in technology, applications and traffic characteristics, the modeling framework enables predictions on the access related energy demands raised by forecast trends in conjunction with accompanying equipment change options. This modeling framework may serve operators of access networks to select network migration paths that are effective in the short term and efficient in the long term. Beyond that overall options for energy efficient and user oriented ICT[2] solutions have been described and evaluated. Finally policy recommendations have been developed supporting the development of sustainable ICT for the domestic sector on a national level.

I Introduction

Both the number of broadband subscribers and the number of end-user devices have been increasing rapidly in the last decade [1] and this trend is expected to continue in the future. Additionally, introduction and a broad use of high-end applications increasingly drive the need for high capacity in access networks. The most complex part of today's Internet is the access network area, which also contributes mainly to the high total energy consumption of the global network infrastructure. According to the vision of the "Internet of Things", it is expected that in the foreseeable future, additionally to person-used applications also a huge number of intelligent, self-communicating devices will communicate with each other over the Internet. All these trends indicate an urgent need for more efficient access networks. Recently, there has been a lot of research effort to assess and improve the energy efficiency of access networks [2]-[9].

Most of the previous research works either concentrate on energy-efficient devices and structures or consider only a part of the complex and heterogeneous access network infrastructure. In most cases, wired and wireless parts of the network are treated separately. In this study, we evaluate the energy efficiency of the entire access network infrastructure by considering both wired and wireless networks as well as the wireless backhaul that is used to connect base station sites to the backbone network. Additionally, we consider end-user equipment, socio-demographic characteristics and application

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[1] Internet of Things (abbrev. IoT): Network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment.

[2] ICT: Abbreviation for „Information and Communication Technologies“

usage to cover all important factors needed to appropriately estimate the energy efficiency of access networks and make projections for future developments.

The paper is organized as follows. The Section II introduces the modeling framework and describes the structures of models used to analyze end-user devices, application usage and access networks. Section III presents some exemplary results of the application of the framework to analyze the energy efficiency of a national-wide access network infrastructure. Finally, Section IV summarizes the paper and draws conclusions.

II Modeling framework

The ultimate aim of the modeling framework presented here is to enable a holistic assessment of access networks and to help understanding complex independencies between socio-demographic trends, technology, applications and usage patterns. It could also serve to indicate potentials and risks of different approaches and to assist policy makers in developing a policy framework towards a sustainable Internet access.

The technical scope of the framework is shown in Fig. 1. The figure illustrates technologies and devices considered in this study. The boundaries of the system under consideration are the interface to the backbone network, i.e. the uplink of the aggregation switch that is usually located in premises of network providers on one side, and users of networked equipment on the other. In the following, we describe three sub models that are used to: i) analyze user behavior and applications ii) predict trends in the end-user equipment sector and iii) evaluate access networks by means of energy efficiency. The three sub models interact with each other to obtain an overall representation of the entire system. For example, development of new end-user devices affects both applications and user behavior, which is also influenced by socio-demographic trends. All these factors influence the bandwidth demand and the traffic pattern at network terminals, which, in addition, have an impact on network design and performance. Similarly, a broad availability of high data rate Internet access and powerful user devices can accelerate the development of new applications and lead to a notable user behavior change.

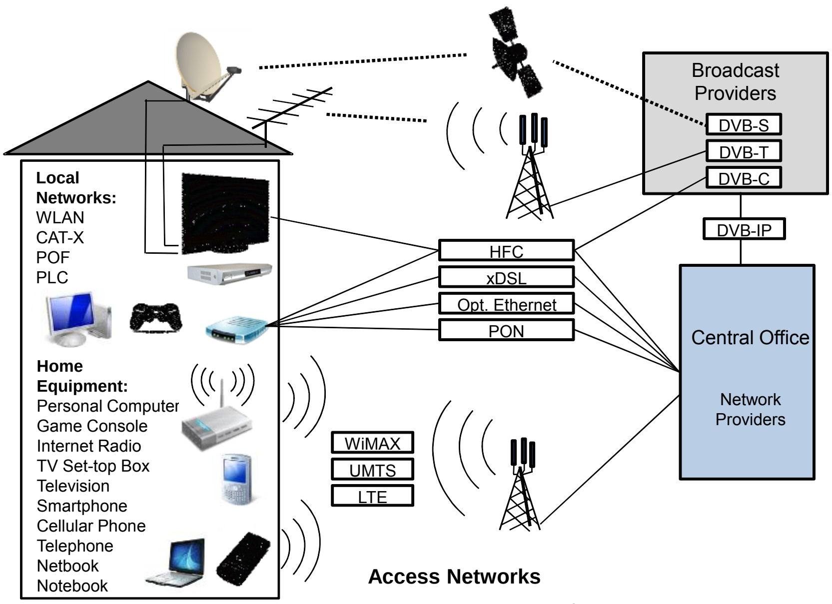


Fig. 1: The scope of the modeling framework[3]

[3] Definitions of used acronyms can be found in the glossary section of this paper.

A. User Behavior, Applications and Traffic

To assess the energy efficiency of different access technologies and deployment scenarios we need to model the traffic that is transported over the provided access capacity. We start with coarse assumptions on the traffic caused by typical applications while in use (Table 1). Next we sketch when and for how long an application is likely used by different user groups. We use five user groups, being children, teenagers, young adults, mature, and the elderly. The usage variation over any day is included by normally distributing the usage likelihood across the day. When doing so, we get usage patterns for each application per user group. Concluding the data base, we rate the popularity of applications for each user group. The application usage (the application mix) can be changed by adjusting the popularity figures, while the application consumption patterns (user behaviors) can be changed by adjusting the usage likelihood curves. The splitting into user groups enables us to flexibly consider diverging trends.

To obtain the utilization of wired and wireless access networks, the traffic caused by an average household and an average mobile customer needs to be calculated, respectively. This is outlined in Fig. 2. Using the socio-demographic distribution we sum up the popularity weighted usage patterns and get the average demand pattern over a day. A tricky challenge results if at certain times of a day the average demand exceeds the capacity provided by a technology, which causes application dependent performance degradation and diminishes the popularity of heavily affected applications. To consider this effect we add a feasibility weighting of applications per access technology. In the end we get a single average utilization curve per technology that can be used to realistically compare the practical energy-efficiency of technologies. The many degrees of freedom preserved are essentially needed to model socio-economic trends.

Table 1: Traffic caused by different applications/services in use

	SERVICES	Downlink [MByte/h]	Uplink [MByte/h]
Voice	Telephone	28,8	28,8
	VoIP (over Internet)	28,8	28,8
	Online Music Streaming (Internet Radio)	72,0	1,5
Video	Video conference	310,5	310,5
	SDTV (Broadcast)	900,0	18,0
	HDTV (Broadcast)	3600,0	75,0
	VoD (Video on demand)	900,0	16,0
	HDoD (HD on Demand)	3600,0	70,0
	Online Video Streaming	720,0	16,0
Data	Classic Internet Services	12,0	3,0
	Online Gaming	28,8	25,2
	File Sharing	52,7	47,7
	Home Office via VPN	41,9	31,4
	Cloud Services	21,1	9,0
	Remote Home Monitoring	0,5	3,0

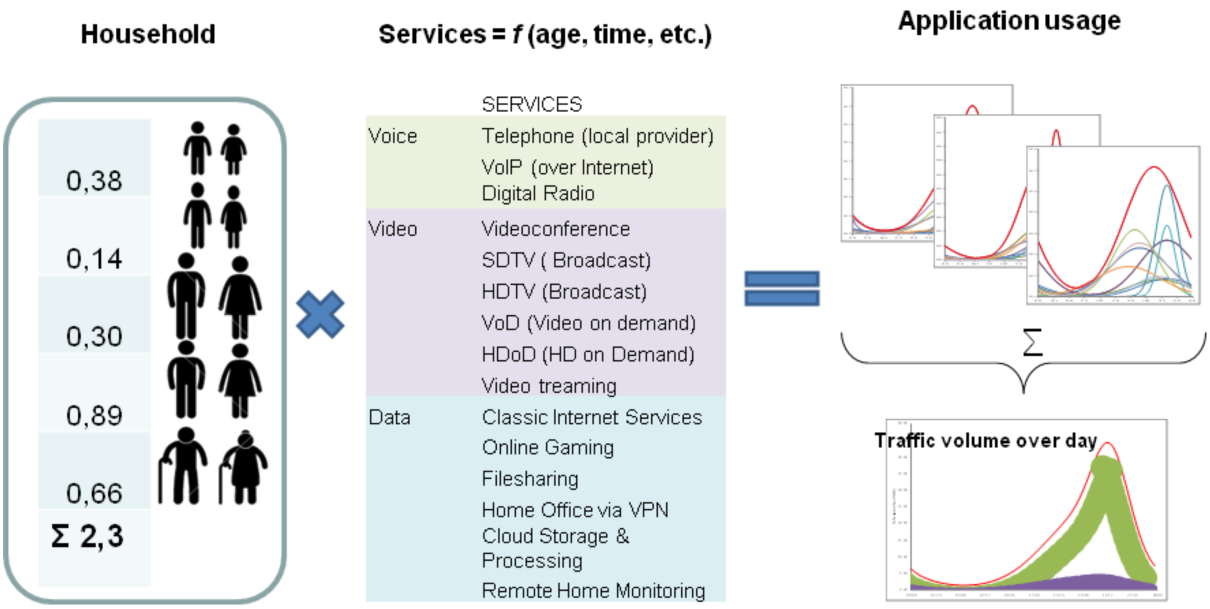


Fig. 2: Access utilization assessment model for an average household

B. Model of Access Networks

The user traffic profiles are determined by the model described in Section II. A. represents an input parameter to the model of access networks. A generic representation of the access network model is shown in Fig 3. The access network is first designed according to the requirements on capacity, coverage, and number of subscribers and the choice of technology. Various technology and application related parameters are taken into account. There are different sub models for wireless and wired parts of the network as well as for the wireless backhaul. The mix of technologies for each sub model is chosen independently, while the input traffic of the wireless backhaul is determined by the traffic aggregated in a base station of the radio access network. The finite capacities of both link and nodes are considered by comparing the actual amount of upstream and downstream traffic to the maximum capacity of each network element. In order to keep the complexity of the model at a reasonable level, the model deals with time-of-day dependent average data rates instead to model the transmission of data packets. Following this approach we are able to perform traffic analysis without using a packet-based, event driven simulator, which would most probably lead to a complex and less scalable implementation. The instantaneous power consumption of the network is determined using the model presented in [7],[10],[11] and according to the characteristics and the number of active network components at each particular time. The results on energy consumption and network performance are combined to obtain the energy efficiency.

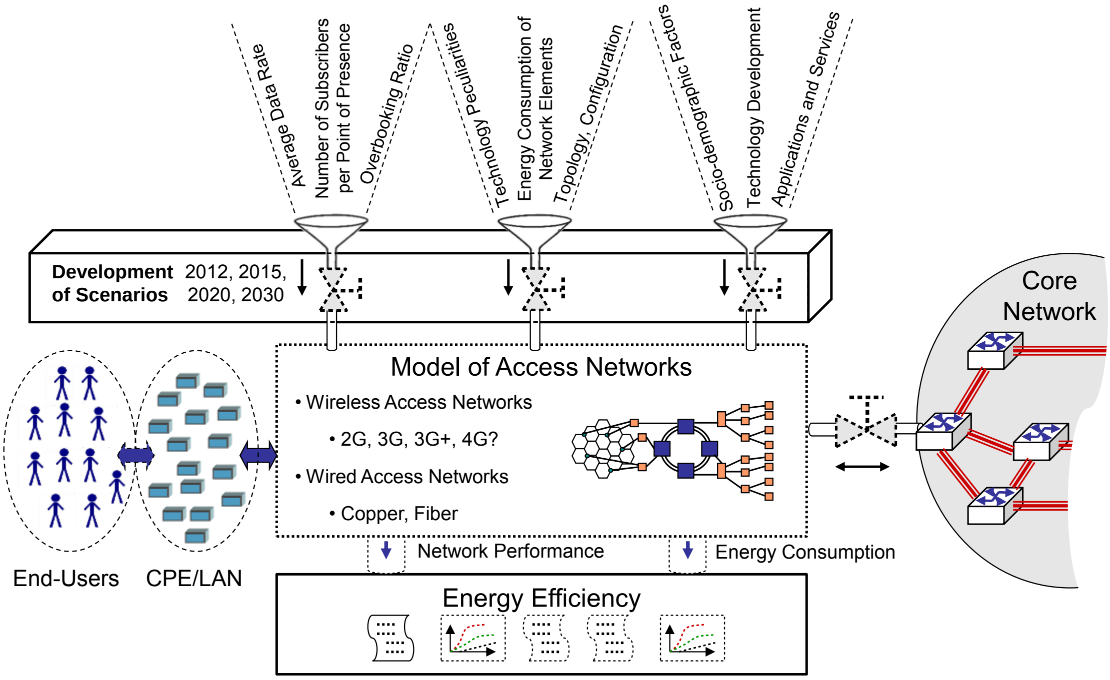


Fig. 3: Generic representation for the access network model

Currently, a typical scenario is to have several network providers acting on the same market. As a consequence, there are usually several networks coexisting and serving their customers within the same region. As a consequence, there are parallel network infrastructures that have to be taken into account. Therefore, an efficient and realistic modeling approach has to be able not only to combine different technologies and network areas but also a number of coexisting networks owned by different network providers as illustrated in Fig. 4.

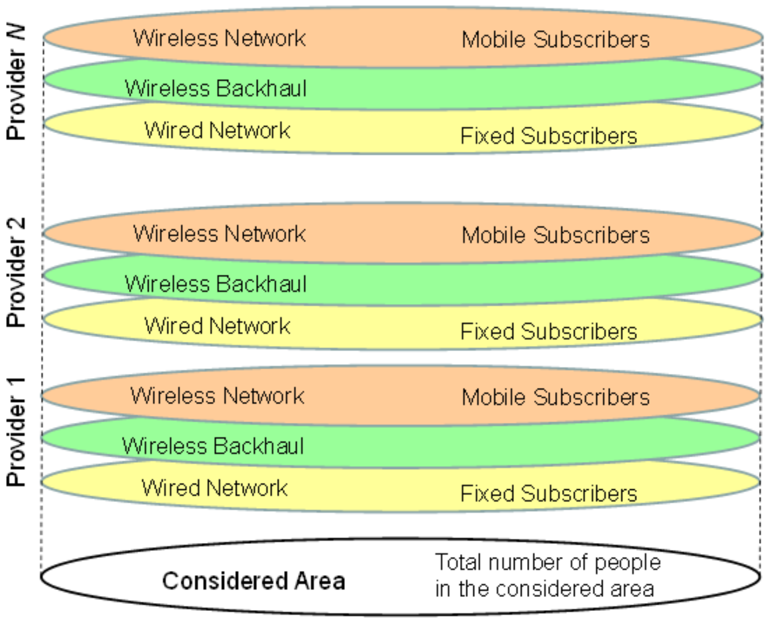
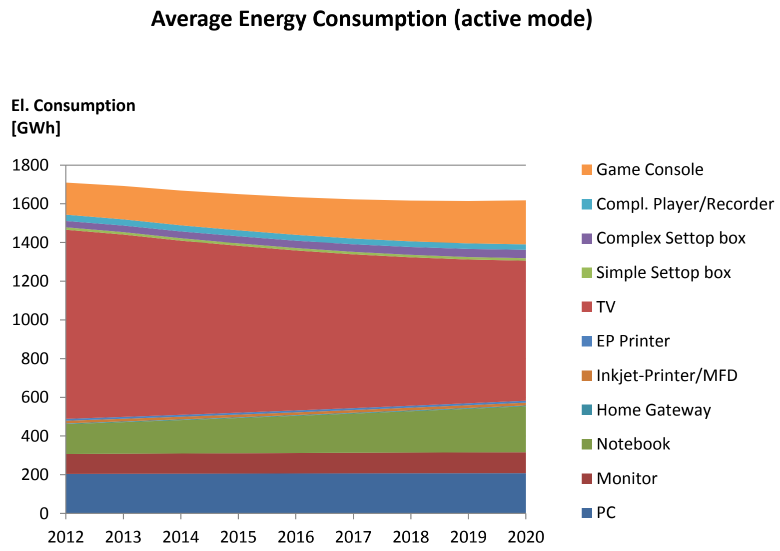


Fig. 4: Multi-provider case

III Case study

In this section, we illustrate the use of the framework for evaluating the energy efficiency of access networks based on a national network infrastructure for Austria. We apply the approach described above to model the region-specific usage patterns for various end-user equipment and applications. An example of a result for energy consumption of different home appliances is shown in Fig. 5. Using a stock flow model and statistical data about usage of electronic devices in Austria, it is possible to determine the current, country-wide energy consumption caused by each type of device and to predict the future trends [12].The results indicate that by far the most energy is consumed by the television set in active mode. The second largest contributor is the personal computer (PC). Thus, the particular attention has to be paid on the methods for improving the energy efficiency of these two devices.

a)



b)

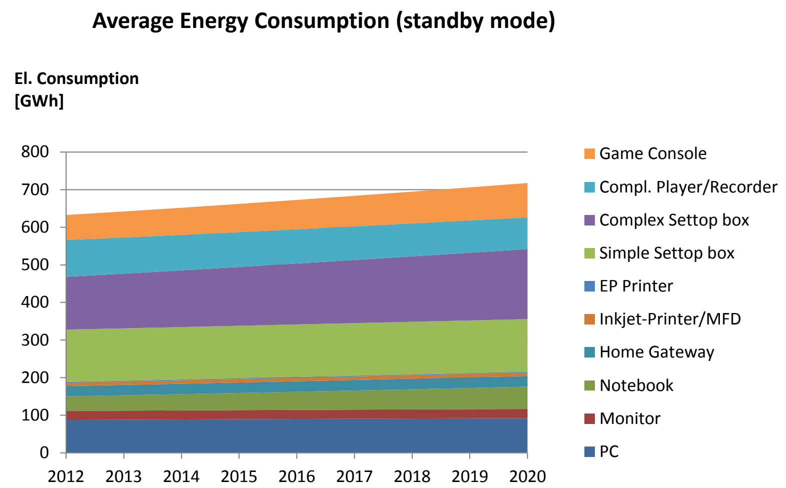


Fig. 5: Projected electricity consumption of various home appliances in a) active and b) standby modes in year 2020 in Austria

According to statistical data of device and application usage as well as the demographic conditions in Austria, we developed traffic profiles for different user types and various combinations of services and technologies. The resulting user traffic profile that describes the time-of-day dependent traffic generated/consumed by a typical user or household is determined following the methodology already briefly described in Section II. A. and illustrated in Fig. 2. Two examples of such traffic profiles for users of UMTS and xDSL networks are shown in Fig. 6. Note that the profiles are different for users of different technologies and are directly influenced by changes in user behavior, applications and their usage patterns as well as by socio-demographic factors. The determination of traffic profiles is an important step in predicting the traffic demand, and thus evaluating network performance for different scenarios.

For the purpose of the evaluation of energy efficiency of Austrian-wide access network, we parameterized the model of access networks according to the data we received from the Austrian Regulatory Authority for Broadcasting and Telecommunications (RTR), Austrian network operators and the Forum Mobilkommunikation (FMK). We also used statistical data about technology penetration, market shares and population densities. The first step was to determine the numbers of mobile base stations required to achieve a desired coverage using the data at the municipality and the federal state levels. There is a very good coverage of both GSM and UMTS networks in Austria, especially in urban and suburban areas. LTE is implemented in some selected areas for test purposes.

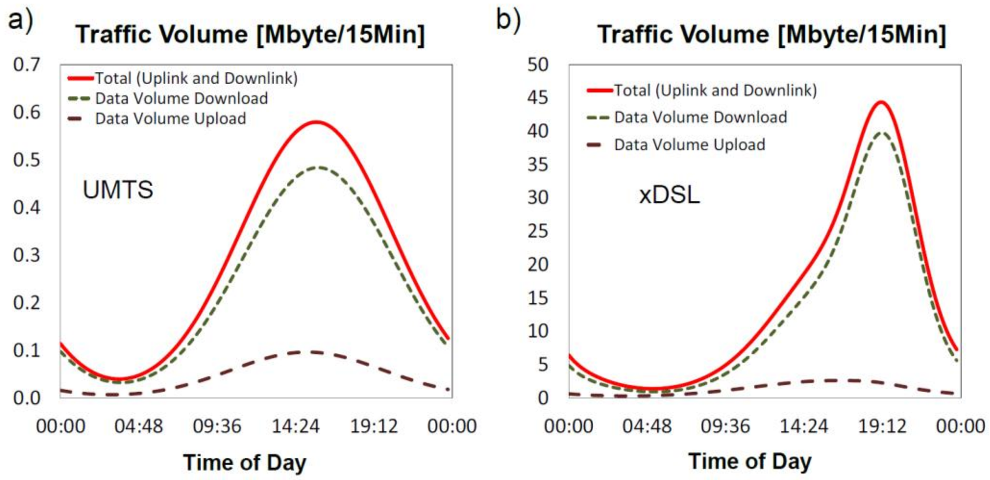


Fig. 6: a) Exemplary user traffic profiles of a) UMTS users and b) xDSL users (households)

An example of the obtained numbers of mobile station sites per federal state is shown in Fig. 7 a). It can be seen from the figure that the numbers of sites obtained by the model are very close to the actual numbers. The difference is mostly below 2% and at most 6.4%. Fig. 7 b) presents the estimated energy consumption of a single-provider radio access network. The unequal energy consumption of radio networks in different states is due to the significant differences in sizes and population densities of the states. The total energy consumption per year of an Austrian-wide radio access network was estimated to be around 270 GWh/a.

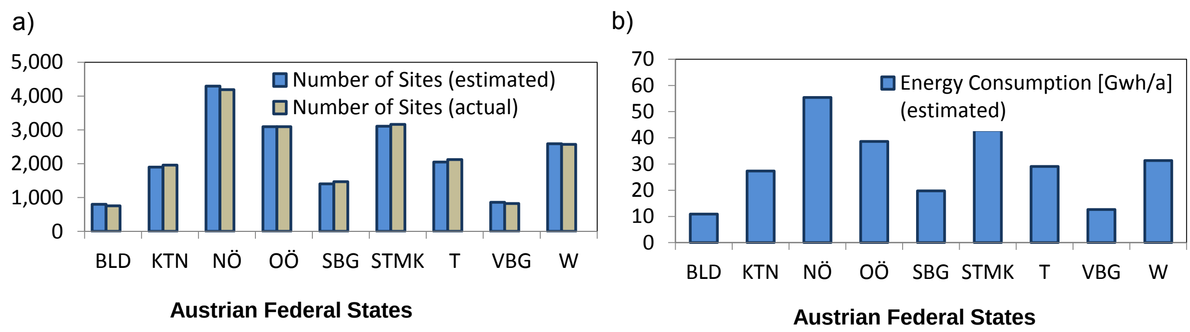


Fig. 7:
a) Comparison of estimated and actual numbers of base station sites in the Austrian federal states. The maximum relative difference is below 6.4 %.
b) Estimated yearly energy consumption of a radio access network in Austria.

Once we have determined the main characteristics of the radio access network, we can model the wireless backhaul. Here we also considered the actual realization of backhaul networks in Austria. The wired access network is designed independently of the requirements for the mobile network. In Austria, the predominant technology for wired access is the digital subscriber line (DSL), while the hybrid fiber coax (HFC) is the second most deployed technology in urban areas. According to our results the entire access network infrastructure in Austria consumes about 1.03 TWh per year. This number includes the consumption of three mobile networks, wireless backhaul and wired networks. In order to assess different access network implementation options with regard to energy consumption we defined three scenarios for future developments. All three scenarios are for the year 2020 and imply an implementation of the goals of the Digital Agenda for Europe [13], which says that the entire European Union (EU) should be covered by broadband above 30 Mbit/s and 50 % of the EU to subscribe to broadband above 100 Mbit/s by 2020.

The business-as-usual (BAU) scenario envisage the use and adoption of currently available technologies for increasing the broadband coverage and limited increase in penetration of the new technologies enabling high-speed Internet access such as LTE and FTTx, predominantly within urban areas. The two other hypothetical scenarios are referred to as “highly energy-efficient” and “energy inefficient”. The highly energy-efficient scenario bases on the assumption that the current network is replaced by a new, high-bandwidth and highly efficient network infrastructure. Thus, LTE becomes the predominant technology for wireless access, while the penetration of FTTH becomes high. The redundancy of network equipment is minimized and the methods for reducing the energy consumption such as alternative energy sources and low-power and standby modes are widely deployed. This scenario provides the minimum possible energy consumption.

The third scenario assumes that new technologies are deployed in a rather energy inefficient manner and the old technologies are kept operating. There are redundancies on the equipment and network levels, which mean that several network providers cover the same area and operate redundant networks. In the energy inefficient scenario, energy-efficient devices and approaches for increasing the network energy efficiency are not used at all.

Fig. 8 presents the estimated energy consumption of the entire Austrian access network infrastructure by 2020. It is evident from the figure that in the BAU scenario the energy consumption increases to 2.9 TWh/a in 2020, which is an increase by a factor of approximately 2.8. In case of an inefficient migration, the energy inefficient scenario, the total energy consumption increases more than 4 times (to 4.4 TWh/a). It is interesting to see that if much attention is paid to energy efficiency and a lot of effort is put into deploying energy efficient components and systems, the high broadband coverage envisaged by the Digital Agenda for Europe could be achieved with almost no increase in energy consumption (at 1.05 TWh/a).

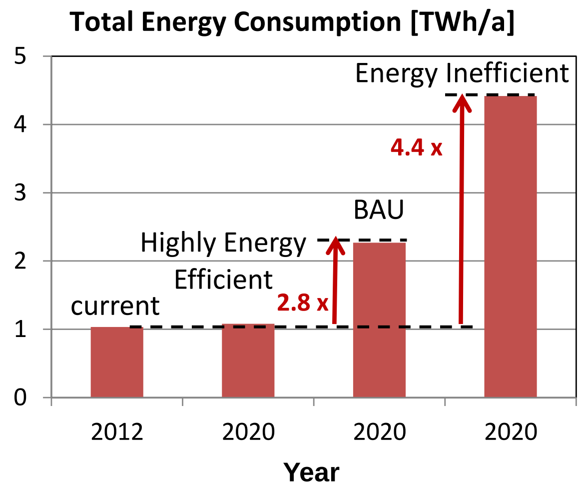


Fig. 8. Prediction of the total energy consumption per year of the overall access network infrastructure in Austria (both wired and wireless networks, multi-provider case).
The curves represent two hypothetical scenarios (highly energy efficient and inefficient) as well as a prediction of the energy consumption in a business-as-usual case.

IV Conclusions and final recommendations

In conclusion, we presented a comprehensive framework for evaluating the energy efficiency of access networks. The framework joins technological parameters and various configuration options with socio-demographic characteristics and varying user behavior. The modeling framework can be used to evaluate different deployment and migration scenarios for both wireless and wired access networks by means of predicted energy efficiency.

In a case study, we applied the framework to evaluate Austria-wide access networks. The results obtained by the model are in a good agreement with the actual data of the network in operation. We assessed different network realization options for achieving a high broadband coverage with at least 30 Mbit/s in 2020. In particular, we considered three scenarios, namely a business-as-usual (BAU) scenario, a highly efficient scenario and an energy inefficient scenario. In the BAU scenario, to cover the most of the populated areas in Austria with a high data rate Internet access one needs to pay with 2.8 times higher energy consumption than it is today. A highly inefficient network planning, deployment and operation could even lead to an increase of energy consumption by a factor of 4.4. However, when concentrating on energy-efficient technologies and approaches and exploiting all their potentials, one could achieve an optimized network infrastructure able to provide both high data rate Internet access to everybody and high energy efficiency. Thus such a high-capacity network would consume approximately the same energy as the current access network infrastructure does.

Aiming at the exploitation of energy efficiency potential a list of recommendations was formulated addressing the policy level as well as telecom network operators. The perspective in elaborating this catalogue reflected the upcoming implementation of Next Generation Access networks even driven by the targets of the EU Digital Agenda:

Area “Network equipment”:

- Use of network equipment (for Base stations – BS and point of presences – PoP) with an extended range for operation temperature, aiming at minimizing the average cooling load throughout the year.
- Implementation of efficient cooling concepts (included forced free cooling and efficient cooling systems
- Use of network components which have the capability being operated in low power modes
- Decentralized energy supply based on renewable energy sources

Area “Network operation”:

- Wide use of infrastructure sharing for base stations of mobile communication networks
- Dynamic adaption of mobile communication networks for efficient coping with load peaks
- Shut down of a share of base stations in multiple supplied areas by coexisting operators and wide use of national roaming to maintain service for all subscribers

Area “Network planning and next generation access roll out”:

- Roll out of publicly financed LTE (4G) network in “white area” (according to definition in Communication of the Commission 2013/C25/01)
- Long term phase out of mature mobile network infrastructure (GSM, possibly UMTS) in the situation of a full scale LTE roll out
- System of incentives or obligations for laying of dark fiber or ductwork

V Acknowledgment

The work described in this paper was supported by the project HOME-ICT funded by the Austrian Fund for Climate and Energy and accomplished within the framework of the program ”NEUE ENERGIEN”.

VI Glossary

DVB-X Digital Video Broadcasting (DVB) is a suite of internationally accepted open standards for digital television. Suffix X represents the generic placeholder, as DVB systems distribute data using a variety of approaches, including: Satellite (DVB-S, DVB-S2 and DVB-SH), Cable (DVB-C, DVB-C2), Terrestrial television (DVB-T, DVB-T2).

FTTx Fibre to the x (FTTX) is a generic term for any broadband network architecture using optical fibre to replace all or part of the usual wired local loop used for last-mile telecommunications. The term is a generalization for several configurations of fiber deployment, ranging from FTTN (fibre to the neighborhood) to FTTD (fibre to the desk). Common types are FTTB (*fibre-to-the-building)* where fibre reaches the boundary of the building with the final connection to the individual living space being made via alternative means, similar to the curb or pole technologies as well as FTTH (*fibre-to-the-home*) where fibre reaches the boundary of the living space, such as a box on the outside wall of a home.

GPRS General Packet Radio Service (GPRS) is a packet-switched technology that enables data communications over GSM network, often described as 2.5G (second and a half generation).

GSM Global System for Mobile Communications (GSM) is a standard set developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second generation (2G) digital cellular networks used by mobile phones.

HFC Hybrid fiber-coaxial (HFC) is a telecommunications industry term for a broadband network that combines optical fibre and coaxial cable. It has been commonly employed globally by cable television operators since the early 1990s.

HSPA High Speed Packet Access (HSPA) is the most widely deployed mobile broadband technology in the world today. HSPA is the terminology used when both HSDPA (D stands for download) and HSUPA (U stands for upload) technologies are deployed on a network. HSPA builds on third generation (3G) UMTS/WCDMA.

LTE LTE, an initialism of long-term evolution, marketed as 4G LTE, represents the fourth generation standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements.

PLC Power line communication (PLC) carries data on a conductor that is also used simultaneously for AC electric power transmission or electric power distribution to consumers. It is also known as power line carrier, power line digital subscriber line (PDSL), mains communication, power line telecom (PLT), power line networking (PLN), and broadband over power lines (BPL).

POF Plastic optical fibre (POF) (or Polymer optical fibre) is an optical fibre which is made out of plastic. POF has been called the "consumer" optical fiber because the fiber and associated optical links, connectors, and installation are all inexpensive.

PON Passive optical network (PON) is a point-to-multipoint, fibre to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises, typically 16 – 128. A PON consists of an optical line terminal (OLT) at the service provider's central office and a number of optical network units (ONUs) near end users. A PON reduces the amount of fiber and central office equipment required compared with point-to-point architectures. A passive optical network is a form of fiber-optic access network.

UMTS Universal Mobile Telecommunications System (UMTS) is a third generation mobile cellular system for networks based on the GSM standard. UMTS uses wideband code division multiple access (WCDMA) radio access technology to offer greater spectral efficiency and bandwidth to mobile network operators.

WLAN Wireless local area network (WLAN) links two or more devices using some wireless distribution method, and usually providing a connection through an access point to the wider Internet. This gives users the mobility to move around within a local coverage area and still be connected to the network. Most modern WLANs are based on IEEE 802.11 standards, marketed under the Wi-Fi brand name.

xDSL Digital subscriber line (DSL, originally digital subscriber loop) is a family of technologies that provide Internet access by transmitting digital data over the wires of a local telephone network. The x is a variable that, in context, is replaced according to the appropriate variety of DSL (such as ADSL, VDSL, etc.).In telecommunications marketing, DSL is widely understood to mean asymmetric digital subscriber line (ADSL), the most commonly installed DSL technology.

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Energy Use Trends, Policies and Savings Opportunities Related to Consumer Electronics

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Abstract

Consumer electronics products consume approximately 10% to 20% of household electricity use in the United States. The number of gadgets in use has exploded and only recently have the energy efficiency community and policy makers begun to fully understand and address the energy use of these products. In this paper, we take a close look at the energy use, recent developments, and savings opportunities related to the TV and computer "ecosystems", with a particular emphasis on set top boxes, video game consoles, and small network equipment. In some cases, the energy use and savings opportunities are larger for the devices connected to the TV and computer, then these devices themselves.

Introduction

While the efficiency community and policy makers have for decades focused with great success on the energy use of residential appliances, heating and ventilation equipment, and lighting, these groups have only recently begun to understand the energy use of consumer electronics and to develop labeling and standards programs to reduce their energy use. Recent US studies by the Fraunhofer Center for Sustainable Energy Systems and the California utility Pacific Gas and Electric estimate that consumer electronics consumed 193 TWh/yr. in 2010 and 13.2% of national electricity use, and 18% of residential electricity use in California in 2006, respectively. [1,2] Test methods to measure the energy use of these products when they are in use and when they are in "standby" modes are being developed and updated as necessary, and studies to better understand the hours of use and duty cycles are just beginning to be performed.

In this paper, we take a close look at the energy use, recent technological and policy developments, and savings opportunities of the TV and computer "ecosystems", with a particular emphasis on set top boxes, video game consoles, and small network equipment.

Televisions

Over the past decade the TV market has undergone a massive and dramatic shift from analog cathode ray tube (CRTs) televisions to digital flat panel TVs that offer superior resolution and a much thinner form factor. When this transformation began in the early 2000's, there was very little information known about the power consumption of these new flat screen TVs. The test method in the U.S. was completely outdated as it was based on static black and white test bars and did not adequately capture the energy used to receive and display digital moving images. U.S. policies were also in their infancy as these products were not covered by state or national minimum energy efficiency standards and the U.S. labeling program ENERGY STAR only covered standby power use in its specification.

The Natural Resources Defense Council (NRDC) and their consultant Ecos conducted an in depth study [3] of TV power use in 2005 based on the usage of a simplified test method that included playback of 2 minutes from the DVD Shrek. Key findings included:

- TV screen size is increasing dramatically and with corresponding increase in TV power use
- Plasma TVs used 2 to 3 times more power in active mode than similar sized CRTs, and often used considerably more power than LCDs. (Note plasma TVs have since become dramatically more efficient and are now much closer to LCD power use.)
- There was a wide spread in the power consumption of similar sized TVs rendering this category as a good candidate for effective labeling and standards policies.

- Americans are watching more hours of TV per day due to increasing number of channels on pay TV, and playing of DVDs and video games. This translates to increased national TV energy use.
- Household energy use for TVs and the equipment connected to them could exceed 10% of a household's electricity bill.

Since this study was completed the industry worked through its trade association CEA to develop an up to date test method (CEA #2043) for measuring active mode power of digital TVs that included a standardized 10 minute clip of digital images to play during the test. A number of policy initiatives were also undertaken in the U.S. including several updates of the ENERGY STAR specification and development of an ENERGY STAR Most Efficient specification that identifies the top 5% most efficient models on the market, rebates offered by some utilities to retailers for sales of ENERGY STAR qualified models and those that exceeded it by x%, and mandatory minimum efficiency standards set by the State of California under Title 20, its appliance standards.

These policies resulted in an immediate change to how TVs were shipped in the U.S. that resulted in energy savings of 10 to 25%. Historically TVs were shipped in their brightest selectable mode, often referred to in the trade as retail or torch mode, to ensure retail clerks who unpacked the TVs placed them on the shelf with a very bright setting. As retail floors are typically brightly lit and because all things being equal consumers often buy the TV with the brighter picture, all TVs were shipped in retail mode. This represented a huge waste of national energy as most consumers do not need such a bright picture setting and are unlikely to change the setting from its default. ENERGY STAR adopted the CEA test method and added a few additional requirements that essentially caused the industry to include a standard/normal picture setting during initial user set-up. The test method and specification also made it harder for manufacturers who continued to ship their TVs in the retail mode by default as this resulted in much higher reported energy values.

Figure 1 below shows the steady and dramatic decline in energy use of 42 inch TVs since this package of policies went into effect. These savings were due to the settings change discussed above, inclusion of automatic brightness control sensors that adjust screen brightness and power consumption based on room light levels, and numerous technical advances spurred by the California standards and ENERGY STAR specifications most notably the switch to more efficient LED backlights.

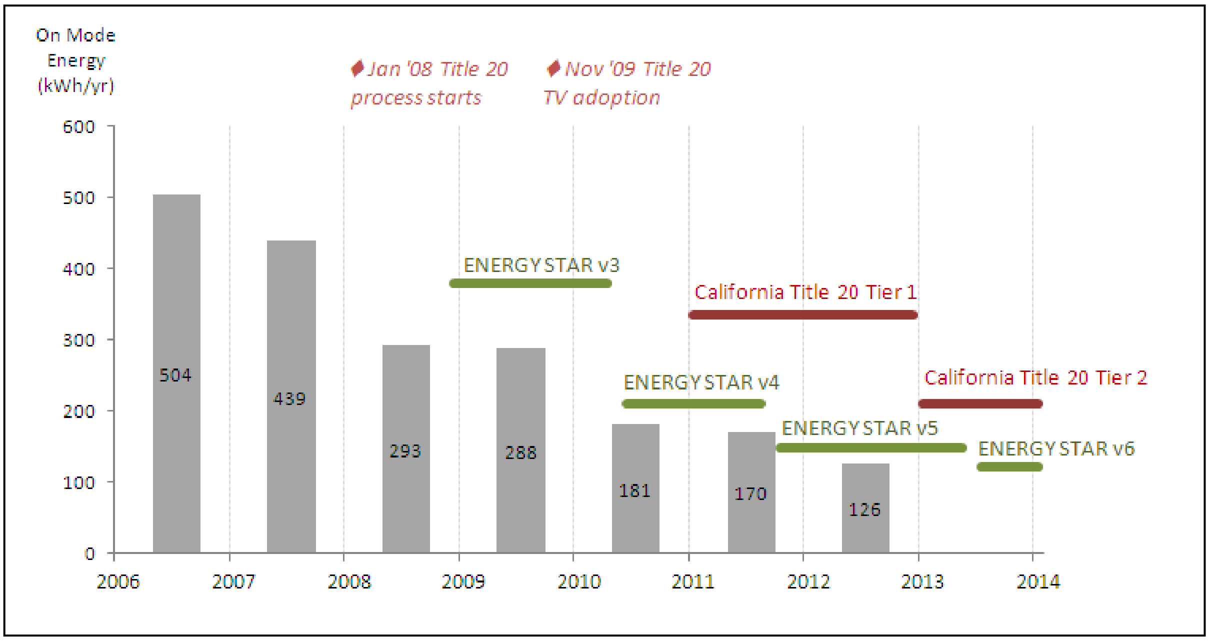

Figure 1: Change in Average Annual Energy Consumption of 42 Inch TVs in the U.S.

Based on modeling done by NRDC's consultant Energy Solutions, the improvements made in TV efficiency from the 2008 base case represent 10 power plants worth of electricity in 2020 and the prevention of more than 200 million metric tons of CO2-equivalent during this period. Consumers will also have saved $27 billion between 2008 and 2020 in the form of lower electric bills. During this time period the price of a new TV has dropped more than 50%, counter to predictions of cost increases made by the industry during standard setting processes in the US.

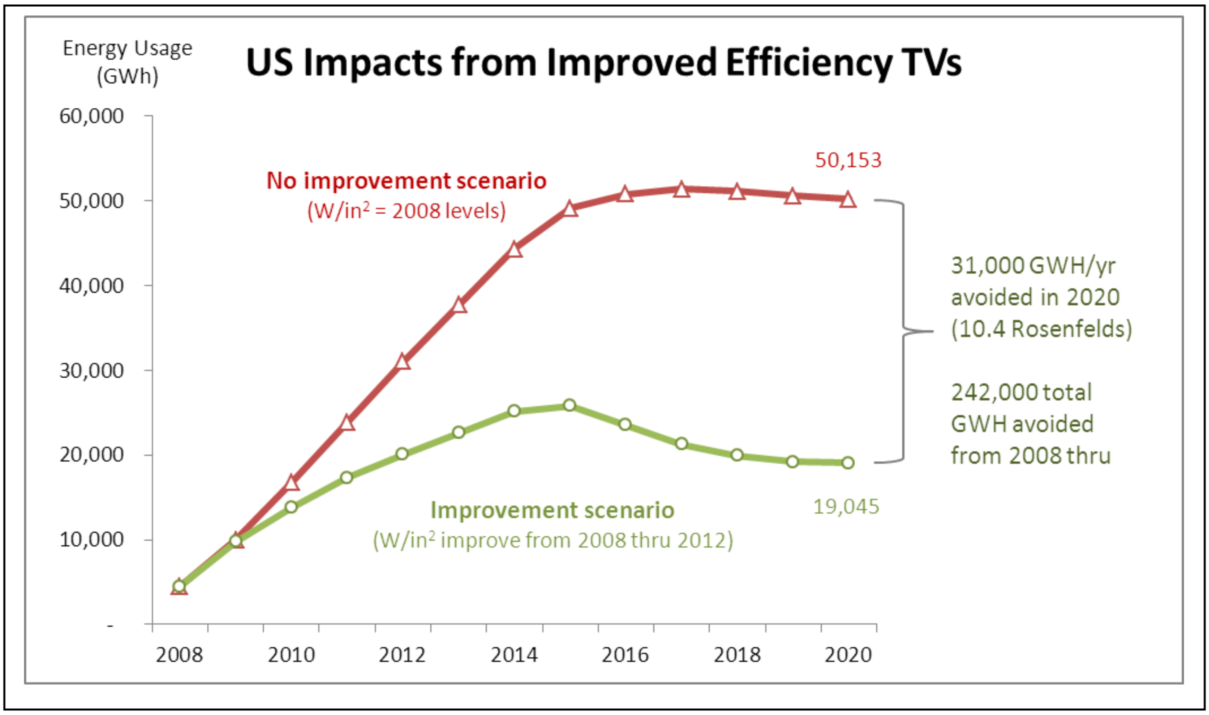

Figure 2: U.S. Impacts from Improved Efficiency TVs

While dramatic improvements have been made to date, future incremental efficiency gains may be achieved through further advances in LED technology, the successful launch of OLED based TVs that eliminate the need for energy consuming backlights and other technological advances. In addition manufacturers and policy makers need to remain vigilant to ensure these hard earned savings are not lost due to new features, if poorly designed, such as ultra hi definition TV, and internet enabled TVs that have extremely high standby power as is currently the case with some implementations of Google TV which consume 24W (number of hours per day varies by manufacturer) of standby power if the Quick Start feature is selected. If this feature is always on when the TV is "turned off", it would account for an additional 166 kWh/yr. which is more than the **total** energy use of most 42 inch TVs today!

With the efficiency gains already made on TVs, a bigger focus is now being made on some of the devices connected to the TV, such as the set top box and video game consoles, which are discussed below. Note: this paper does not address the growing trend of sound bars and surround sound systems which provide superior sound quality to that provided by the TV, which has very little remaining real estate to include speakers.

Set Top Boxes

A set-top box (STB) enables consumers to receive pay TV signals from their service provider – the cable, satellite or telephone company. In the United States there are approximately 160 million installed STBs and approximately 85% of U.S. homes subscribe to some form of pay TV. According to a 2010 study [4] performed by the NRDC, STBs in the U.S. consumed approximately 27 billion kilowatt-hours of electricity annually which is equivalent to the annual output of nine average sized (500MW) power plants. As a result of their operation, STBs were responsible for 16 million metric tons of CO2/yr.

Perhaps most compelling was the fact that STBs cost U.S. households more than $3 billion per year in the form of monthly electric bills, with $2 billion of that when the device is turned "off". Unlike almost all other products on the market, pressing the on/off button on the STB remote did NOT result in a significant change in the STB's power consumption (e.g., 30W on, and 29W in standby mode). Below we provide further detail on the findings of the NRDC study and discuss efforts underway to reduce the energy consumption of these devices.

Market Background

In the U.S., the service provider is the purchaser of the STB and they install the STB when a customer signs up for service. The service provider leases the box to the customer or the cost of the box is somehow configured in the monthly fee/lease agreement. As the customer and not the service provider pays the electric bill, the STB's energy consumption has historically not been a design priority for this industry.

Other trends in the U.S. worth noting are:

- 65% of the homes in the U.S. have 3 or more TVs and the typical pay TV customer has 2.4 STBs in their home.
- STB Digital Video Recorders (DVRs), which allow consumers to conveniently record and playback shows, have become extremely popular. Until recently some service providers had promotions that included installation of a DVR on each TV in the home that was hooked up to their service. As a DVR consumes approximately 40% more energy than a standard set top box, this trend would result in rapid growth of household STB energy use.
- Internet Protocol Television (IPTV) provides a third service provider option for U.S. pay TV subscribers. These services are typically offered by the telephone company and are gaining market share from the satellite and cable companies.

STB Power Use Data and Analysis

As part of the 2010 NRDC study, NRDC's consultant Ecos Consulting (now called Ecova) made field measurements of the power use of 58 installed STBs – ranging from the most basic standard definition (SD) STBs, to full function STB DVRs with high definition (HD) and multiple tuners. These STBs were from a range of manufacturers and testing was done on several service providers. Below we present some of the measured data and analysis from the study.

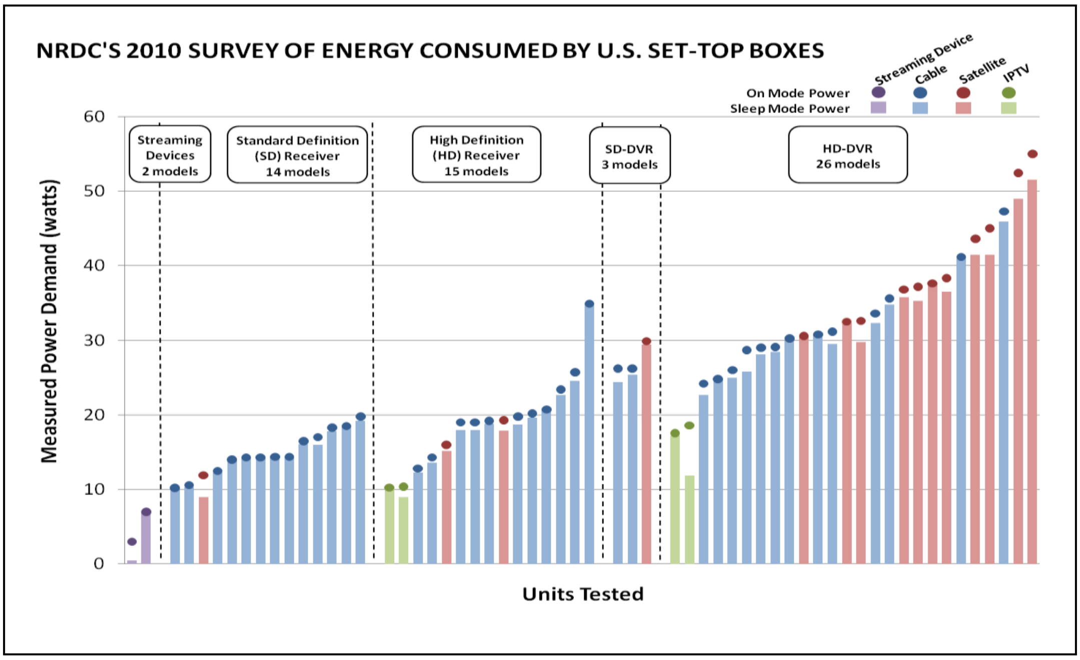

Figure 3: NRDC's 2010 Survey of Power Consumed by U.S. Set-Top Boxes

The per model test results for each of the models tested are shown in Figure 3. As expected HD boxes consumed a little more power than SD boxes and DVRs consumed more power than conventional STBs. With a few exceptions, there was very little difference between on and sleep mode (e.g., power use when power button on remote is turned off) power. The best models showed a 7 Watt difference between on and sleep mode which was probably due to the STB spinning down the DVR's hard drive when no recording or playback was occurring.

Converting this data to annual energy use values, one can see that annual energy use ranged from 100 -200 kWh/yr. for an HD STB and 200 to 400 kWh/yr. for HD DVR. The STBs provided by the IPTV providers used significantly less power than those offered by the cable and satellite companies.

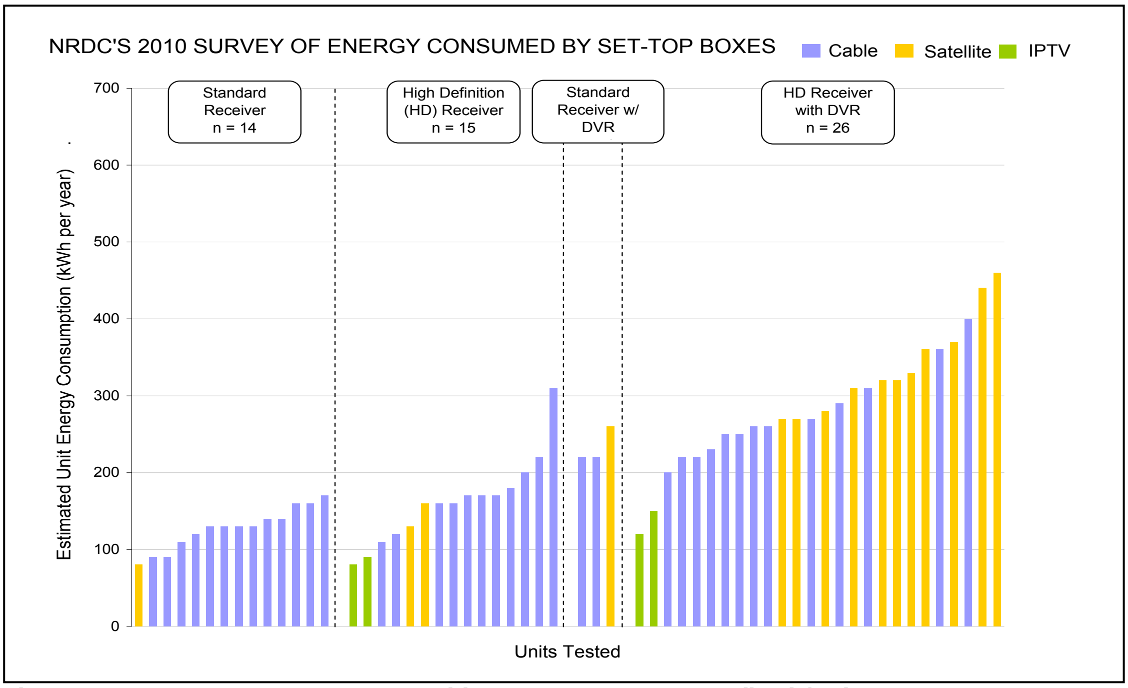

Figure 4: Annual Energy Consumed by US Set-Top Boxes (kWh/yr.)

If one assumes that a typical subscriber has a HD-DVR STB on its main TV and a HD STB on the home's second TV, the annual household STB energy use is 446 kWh/yr. To put this into perspective, the annual energy consumed by a typical household for its STBs is more than a new ENERGY STAR rated mid-sized refrigerator (21 ft3) and the average HD-DVR STB consumed more energy per year than the new 42 inch LCD TV it was connected to. Figure 5 below provides this comparison in a graphical format.

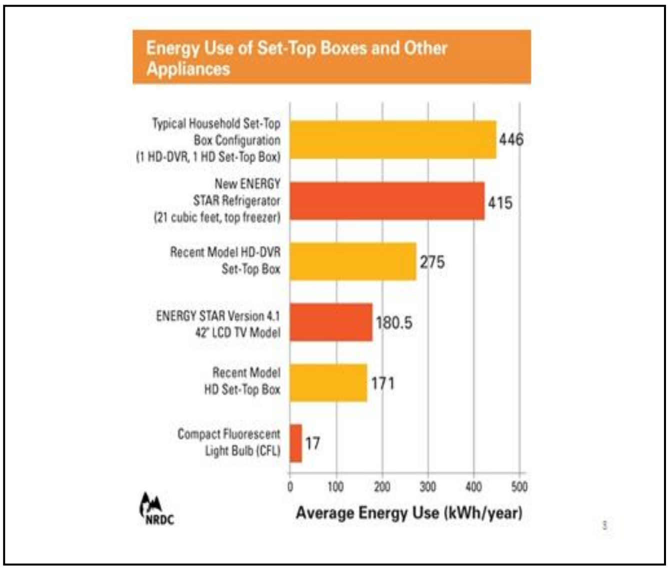

Figure 5: Comparison of Energy Use of Set-Top Boxes with Other Appliances

It should also be noted that customers who physically unplug their STB or connect their STB to a power strip that is turned off at night in order to reduce their electric bill and carbon footprint, will experience delays of 30 seconds to as much as 5 or more minutes to receive full service when they return. This slow wake or recovery time has served as a barrier for manufacturers to implement a low power deep sleep state for STBs when the user is neither watching nor recording a show. In addition, a disconnected DVR will not be able to wake to record prescheduled shows.

Progress/Developments Since 2011

There has been a lot of activity in the past two years by both U.S. service providers and STB manufacturers to reduce the energy consumption of their devices. These include:

- *Establishment of updated ENERGY STAR specifications* – The U.S. Environmental Protection Agency (EPA), which manages the voluntary ENERGY STAR labeling program, issued an updated specification, Version 3.0, for STBs that requires new STBs to use approximately 30% less energy. A list of qualified products can be accessed at http://downloads.energystar.gov/bi/qplist/Set_Top_Boxes_Product_List.xls?8955-cdde. EPA is also in the process of finalizing Version 4.1 which should deliver an additional 25% or more savings and is due to go into effect in the first half of 2014.

- *Cable industry light sleep initiative* – In March 2012, the cable industry announced their plans to push a software update to their customers' boxes that will add a "light sleep" capability to 10 million STBs currently in the field. These boxes will enter light sleep after the user hits the power button or via a new auto power down (APD) feature whereby STBs left on will automatically enter light sleep after extended period of user inactivity (typically 4 hours). Per Cable Labs, this will save an estimated 35 kWh/yr. per DVR.

- *Move to whole home solutions* – The satellite industry has begun to shift their business model from having a DVR or standard STB on the second and third TVs in the home. Many new customers are now receiving a whole home DVR, that uses slightly more power than a traditional DVR, for their main TV and a thin client on each of the additional TVs in the home. The TVs with thin clients receive their content from the whole home DVR. Today's thin clients use approximately 8W when on and have sleep mode power of 7.5W. As the thin clients are NOT connected to the service provider's "head end", they should be able to achieve sleep mode power levels of 1 to 2W with a quick wake time, providing additional savings.

Game Consoles

According to a recent study by the International Data Corporation (IDC), there will be more than 250 million video game consoles in use by 2015.[5] The latest video game consoles offer superior gaming experiences and often include other features, such as online gaming and the ability to play DVDs and stream movies and music. There are only three game console manufacturers Microsoft, Sony and Nintendo and their current products are the Xbox 360, PlayStation 3 and Wii, respectively

As there was no publicly available data on the power consumption of game consoles in their main modes of operation, NRDC performed the first ever comprehensive study of the energy use of these devices in 2007.[6] NRDC's consultant Ecos Consulting (now Ecova) purchased each of the currently available game consoles on the market and measured their power consumption in the laboratory. NRDC and Ecos developed their own testing methodology for this study as no industry test methods existed for this category. Since then NRDC has worked with the game console industry to develop consensus test methods and has measured the energy use of updated versions of these devices. The power consumed for active game play, idle/navigation and off modes is shown in Figure 6. The Xbox 360 and PS3 consumed a factor of 3 to 5 times more power for game play than their predecessors the Xbox and PS2 did five years ago. Since the initial launch, the industry has taken advantage of the efficiency gains that are achievable due to more efficient chips and the smaller power supplies that can then be used and has dramatically reduced the power consumed by these devices in all operating modes.

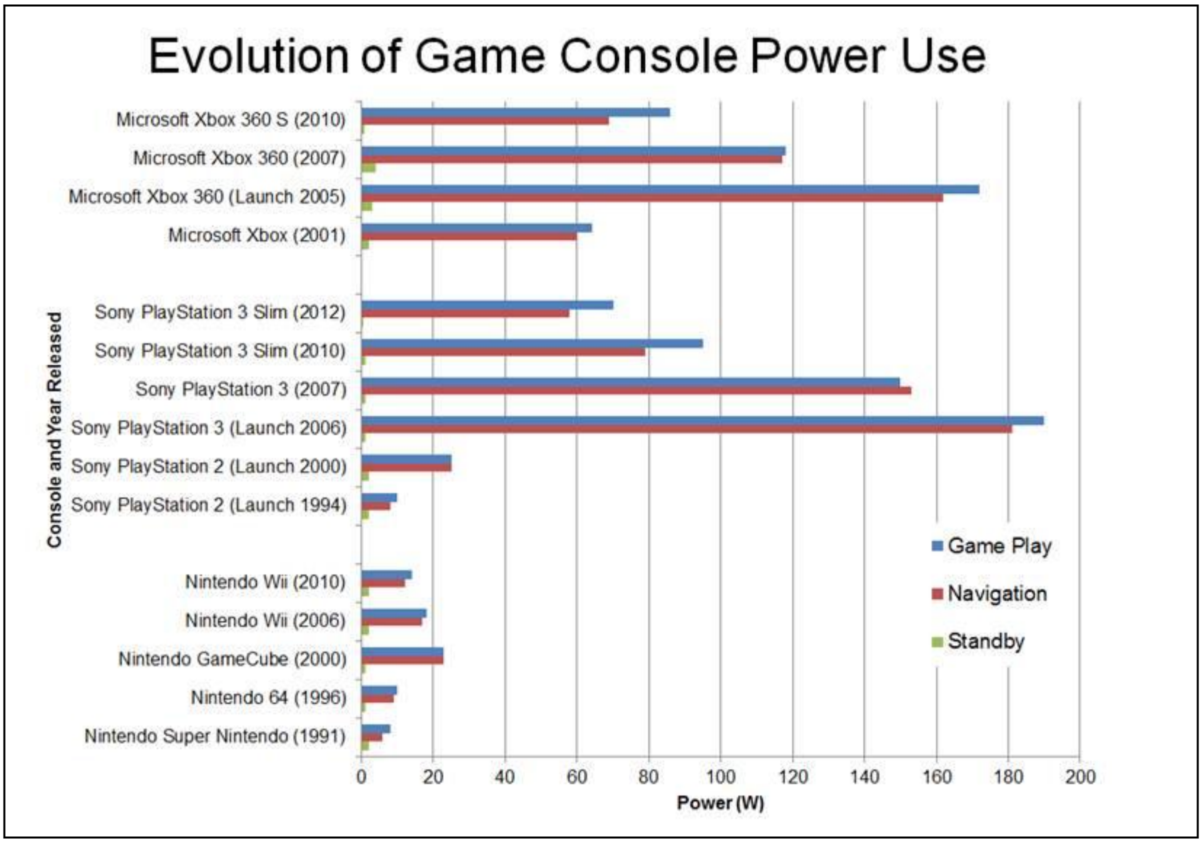

Figure 6: Evolution of Game Console Power Use

One of the most important findings from our study was that these consoles continue to consume near full power levels if the device is left on. While no publicly available data exists on the percentage of devices that are left on, there is a lot of anecdotal evidence that some consumers leave their game console on accidentally (turn off TV but forget to turn off game console) or deliberately because they may lose their place in the game if the device is turned off. Users who leave their PS3 or Xbox 360 console on all the time will consume 1 to 2 new refrigerators worth of energy per year depending on the year they bought their console. This translates to an extra $50 to $100 plus per year in electricity costs.

Microsoft's Xbox 360 did come with a built in auto power down (APD) feature but it was shipped disabled. As such only the most dedicated and curious consumers would know about this feature and go into the menu to turn this feature on. A few years ago, Sony pushed a software update on to existing PS3 models that were connected to the internet that included its own APD feature. This feature had an awkward user interface which likely discouraged users from using it in Game Play and Media Play modes. We understand both devices will now ship with APD enabled by default..

Another interesting finding from this study and follow-up measurements is that game consoles consume considerably more power to stream a movie than a stand-alone Blu-Ray player or an internet streaming device such as Apple TV. This is of particular relevance as Sony and Microsoft are actively promoting use of their devices to access content over the internet to enable customers to stream video via services such as Netflix. In fact, at a recent conference a Microsoft executive (http://news.cnet.com/8301-1023_3-57578389-93/microsoft-to-sell-mediaroom-iptv-business-to-ericsson/) stated that the majority of its 76 million worldwide users spend more time viewing entertainment than playing games. With more scalable processors or a dedicated video processing chip, significantly lower media play power could be achieved in the next generation consoles. Note the recently launched Nintendo Wii U requires 50% less power to display an HD movie than the current PS3.

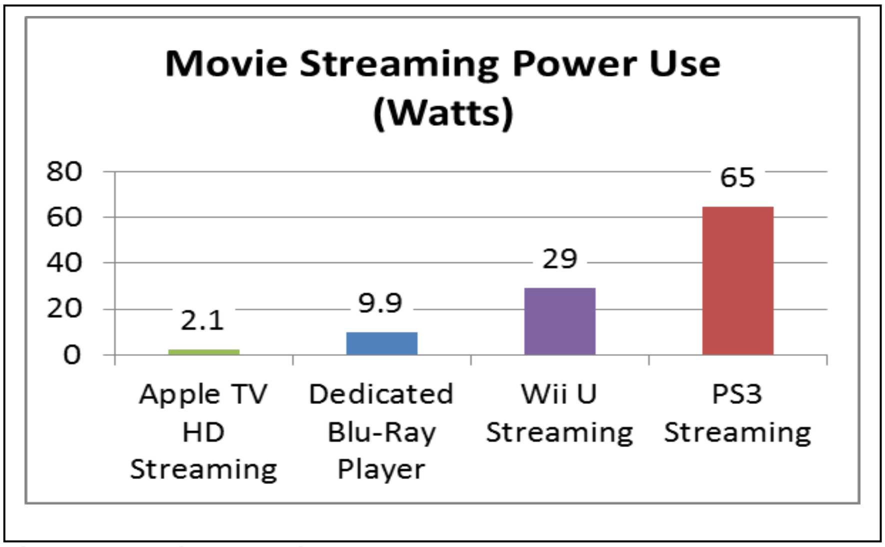

Figure 7: Movie Streaming Power Use

The EPA has recently released a specification under its ENERGY STAR recognition program and it includes power limits for navigation, media play and standby modes. A copy of the specification and test method can be viewed at: http://energystar.gov/products/specs/sites/products/files/Final%20Version%201%200%20EPA%20Voluntary%20Criteria%20for%20Energy%20Efficient%20Game%20Consoles.pdf. One of the key energy saving aspects of the specification is the requirement for new consoles to include an effective APD feature that is shipped enabled and does not require the user to "opt in" for it to work.

Computers

There are approximately 260 million installed computers in the U.S. and per NRDC estimates they consume roughly 80 TWh annually, or 2 percent of U.S. electricity end-use. The energy consumed by these computers and associated monitors is equivalent to twice the annual electricity use of all the households in New York City.[1]

Over four fifths of that energy today comes from desktops.

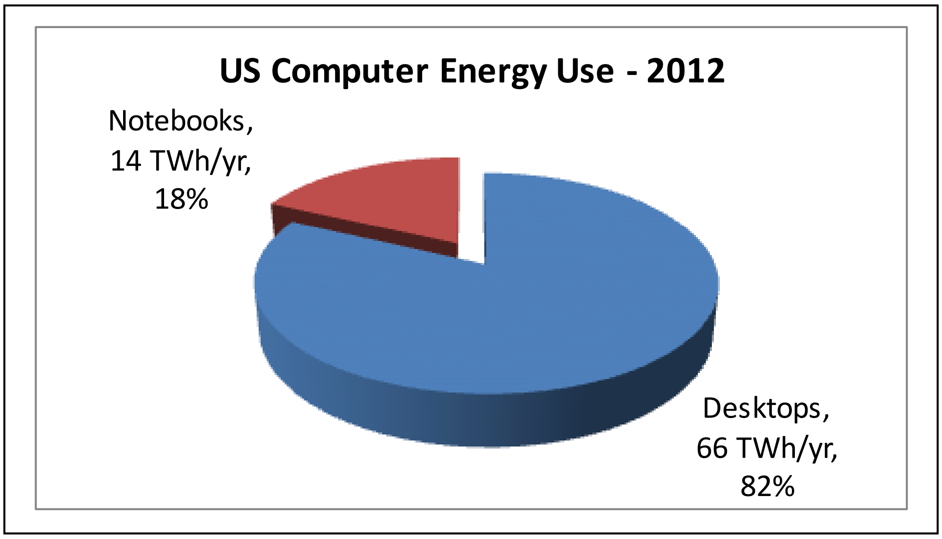

Figure 8: U.S. Computer Use in 2012

While the current stock of desktop computers is roughly split 50/50 with notebooks, this is due to change significantly as sales of notebook computers outnumbered sales of desktop computer by a

[1] This calculation includes an estimate of active mode power use and the power impacts of displays, which are not accounted for in the Energy Star test method.

two-to-one margin in 2012. This will take a while to make its way through the installed base as desktop computers tend to last 5 years whereas notebooks are replaced every 3 years. Two other industry trends are the fast adoption and growing sales of slates/tablets and all-in-one computers (desktop with integrated monitor like the IMac).

Figure 9 below shows the typical energy use of different types of computers. As slate/tablets and notebooks are portable devices and are designed to maximize battery life, these devices have been designed with energy efficiency as a priority. Most desktops are viewed by some as having unlimited supplies of available electricity and historically have not initially received the most efficient components/designs.

Despite the market trends towards these other devices, desktops are not expected to disappear anytime soon: both consumers and businesses still buy desktop computers for reasons ranging from performance to security, reliability and upgradeability. Desktops will continue to be responsible for the majority of aggregate computer energy use for most of the decade because a typical desktop still uses 4 to 5 times as much energy as a typical notebook.

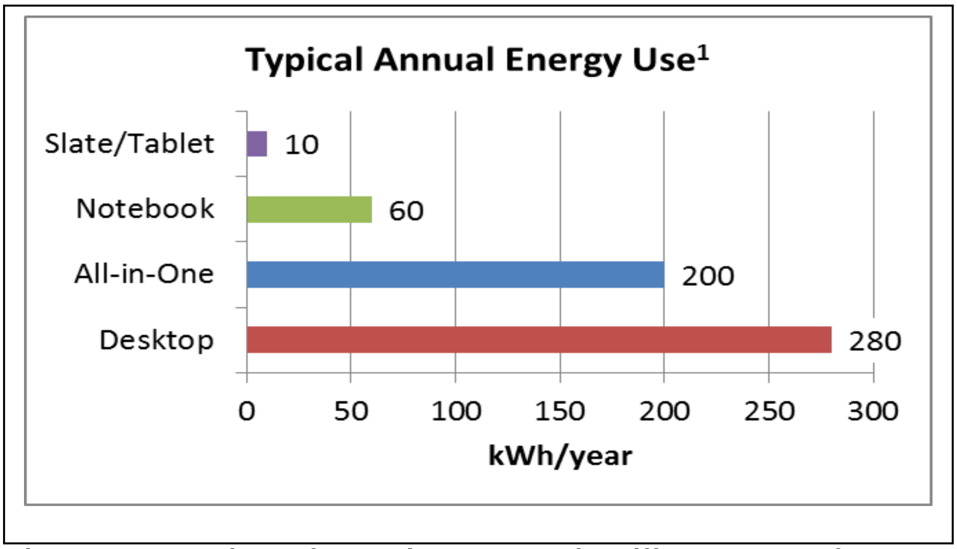

Figure 9: Comparison of Annual Energy Use by Different Types of Computers Including Display

Note: iPad 3, typical 2012 notebook, all-in-one, desktop. Typical display energy included. Power management not enabled for half of computers.

The biggest near term priorities should be to dramatically improve the energy efficiency of desktop computers and to harvest readily achievable incremental savings that can be obtained for laptop computers. In addition all in ones should be encouraged to incorporate notebook technology due to its small form factor and the need for heat management, and the energy savings it would provide. The key opportunities to reduce computer energy use are summarized below:

Efficiency Opportunities

There are many opportunities for energy savings on desktops, such as incorporating mobile components, more efficient power supplies (over half of U.S. desktops still feature power supplies that are roughly 70% efficient at typical operating point, wasting 30% or more of the energy used before it even reaches the rest of the computer system), more efficient disks, and graphics cards that scale power down when little or no graphics processing is required.

Notebook efficiency opportunities generally include the adoption of tablet power-saving technology, such as higher motherboard integration, more efficient power supplies and displays, switching from discrete to integrated graphics when little graphics processing is required, and tablet-like sleep modes that can resume in milliseconds, dramatically reducing idle-mode power use.

Power management

Setting the computer to go to sleep after an extended period of user inactivity is perhaps the largest, yet most challenging energy saving opportunity: a computer without power management uses three times as much energy per year as the same computer with power management enabled. Most manufacturers now ship their products with power management enabled by default, however this is not as effective as it needs to be: the majority of computers rapidly end up with power management disabled for a variety of reasons such as user inconvenience or software applications which disable/interfere with power management settings. Given the market imperative of long battery life in tablets, the industry has successfully solved this issue in devices that are used mostly on battery. Solving it in desktops and notebooks will require a real commitment and collaboration by hardware manufacturers, operating system vendors and application developers to remove the barriers that currently prevent computer power management from working as effectively as it does on tablets/slates.

Small Network Equipment

In the U.S. today, there are approximately 145 million small network equipment (SNE) devices used to access the internet and move content around our homes. The most common of these devices are modems, which connect a household to its service provider; wireless routers, which connect computers, printers, tablets and other connected devices within the household; and combination devices called gateways, which perform both of these functions and sometimes provide telephone service as well. NRDC and its consultant recently measured the power use of these devices to better understand the per-box and national energy use of these devices.[7] The key findings from the study include:

- The household energy use for SNE is just under 100 kWh/yr., which is more than the energy use of a new 32 inch ENERGY STAR TV and roughly 30 times more than a smart phone.
- The energy use of these little boxes adds up as SNE consumed 8.3 billion kilowatt hours of electricity consumed annually, which is equal to the output of three large, coal-burning power plants (500 MW). The result is an estimated 5 million metric tons of carbon dioxide emissions each year, equivalent to the pollution from the tailpipes of 1.1 million vehicles.
- Replacing today's inefficient devices with equipment that is just 25 percent more energy efficient could save 2.8 billion kilowatt hours of electricity—or about $330 million worth of customer energy bills—annually.

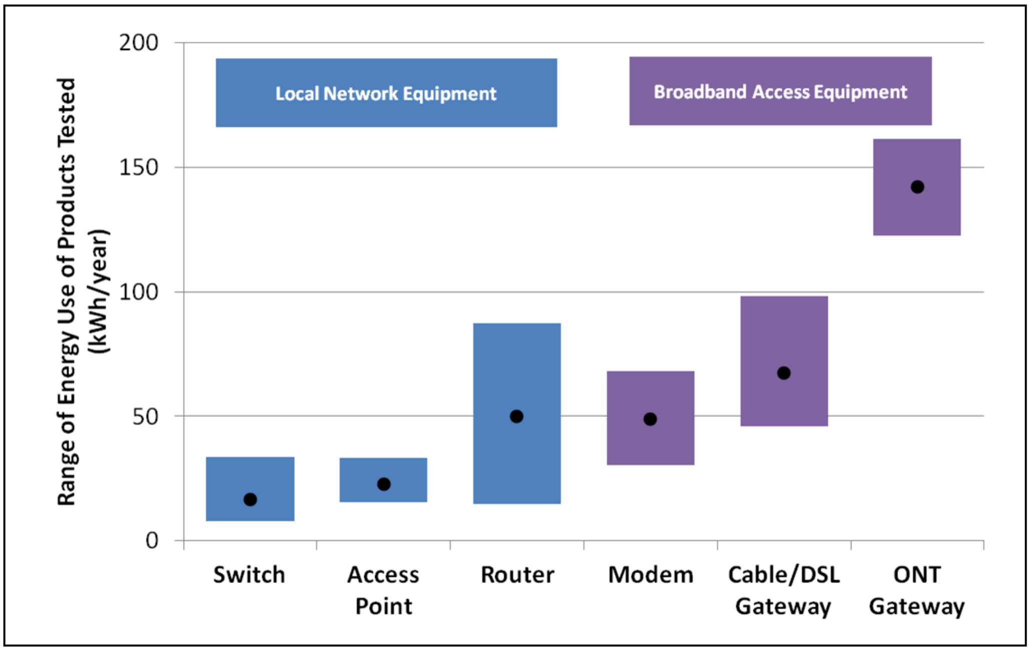

Figure 10: Annual Energy Use of Various Small Network Equipment

Most small network devices on the market today draw the same amount of power when sitting idle, ready to transmit data, as they do when transmitting large amounts of data at high data rate.

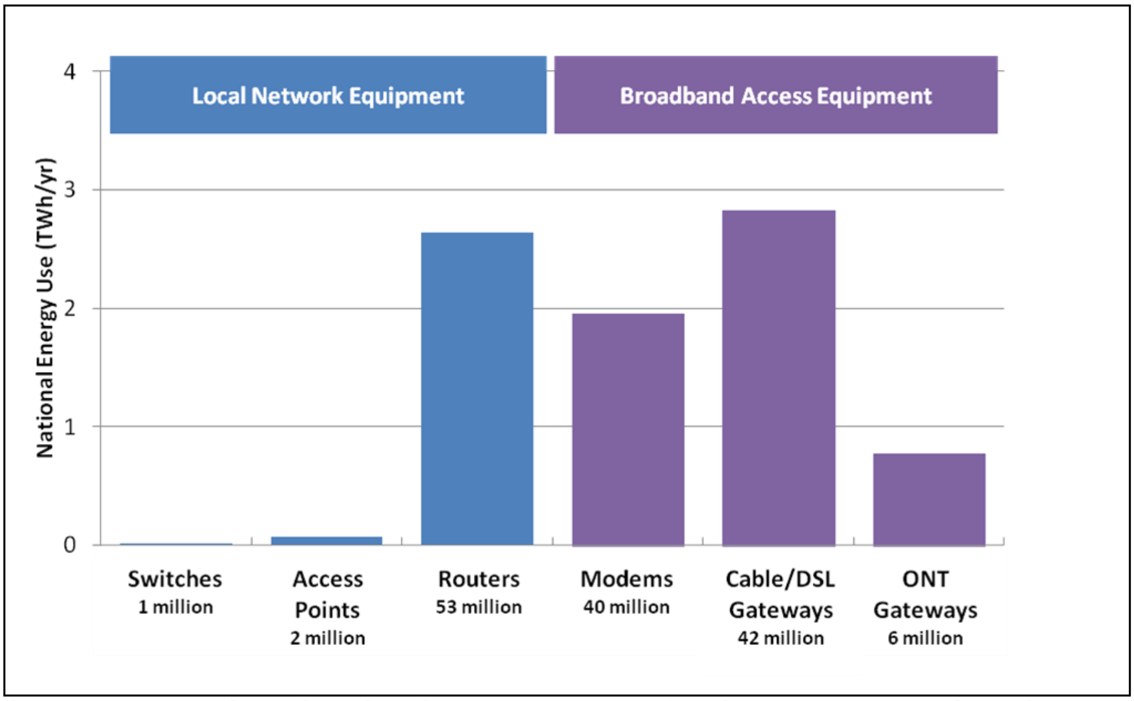

Figure 11: Installed Stock and National Energy Use of Various Small Network Equipment

Deployment of a new protocol commonly called Energy Efficient Ethernet (EEE) and other power scaling technologies incorporated into low power designs available today would allow network equipment to reduce their energy consumption when they are not actively transmitting data. When designed properly, these devices would be able to wake almost instantly and preserve a user's expectation of accessing content from the Internet immediately.

Network equipment manufacturers including D-Link, Motorola, TRENDNet, Sapido and LevelOne are already implementing EEE and other proprietary power scaling technologies in some of their small network devices. A new ENERGY STAR specification program for small network equipment coming in 2013 will highlight products that use less energy and incent manufacturers to sell products that implement EEE. When purchasing new network equipment, consumers should look for products that have the ENERGY STAR logo and EEE, designated by its standard number 802.3az.

The market is also moving towards faster data transfer rates of 1 Gigabyte per second or more and other features that offer greater functionality such as dual-band Wi-Fi, VDSL and DOCSIS 3. This trend heightens the importance of accelerating adoption of efficient SNE designs.

Conclusions

Consumer electronics and their energy use are changing rapidly. The trend has been for products to have high energy use when first introduced and for their energy use to go down over time. This reduction is often due to the shift to new lower power consuming and power scaling chipsets and the resultant energy savings achieved by moving to smaller power supplies. Much of the recent savings for TVs and monitors is due to the shift to LED backlights. Minimizing energy use tends to be a design priority for mobile and portable products in order to maximize the length of time a battery can last before it needs to be recharged. The move from desktop to laptops and tablets will result in significant energy savings.

We also found that settings and user interfaces can make a huge difference in how much energy a product consumes in the field. Some of the power-saving features were shipped-disabled, such as the auto power down feature in video game consoles, resulting in significant missed energy savings. For TVs and displays, the picture mode/brightness settings can significantly impact TV energy use. In addition, we can expect to see more and more products in the home connected to the network. Again, careful attention must be paid to make sure these connected devices do not use excessive amounts of energy while in standby.

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Audio/Video Inter-Device Power Control

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Abstract

There are many new digital communication technologies for procuring and displaying audio and video (A/V) content, and these are evolving rapidly in capability and integration into products. These enable new usage models for moving streams of A/V content among devices in a local network. A challenge this raises is ensuring that products do not remain fully on when they are not needed (often for hours or days between use) which can waste large amounts of energy. A near-term challenge is to create an architecture for how products should interact with respect to A/V content streams to maximize both user amenity and energy savings. Commonality across technologies and products is critical for this to succeed. In today's technologies, a content stream is either active or does not exist. This paper proposes a mechanism to address this problem – "sleeping streams". They have long-term persistence, going into a sleep state between uses, much as devices do when not in use. A stream that is asleep can be readily woken by any of the devices involved in it or by select external devices. This in turn should wake all devices needed for the stream to operate. When a device observes that it is involved with no active streams for a period of time, it can go to sleep. Knowledge of the stream and ability to control other devices, is distributed, not central. This paper addresses details of the concept, what it implies for existing and future A/V technologies, and the role of energy policy.

Introduction

Audio and video devices in U.S. homes are estimated to consume about 140 TWh/year [1]. The portion of this from devices on but not in use is not known, but even if it is only 10% of this, that is well over $1 billion/year in wasted energy. As the mechanisms described in this paper generally do not increase the manufacturing cost of products, attention to this topic is clearly merited.

Audio/Video systems today are of great variety in vintage, technologies, and size. While this paper primarily considers what power control of these devices should be like in future, with new devices, the current devices and context greatly influences that future in many ways.

A/V systems provide people with entertainment from traditional television broadcasts, subscription TV services, pre-recorded content, and, increasingly, from the Internet. These systems enable many different usage scenarios requiring different sets of devices to be on and active. With many devices, multiple users, and evolving technology, it is easy for devices to remain on long after the time they are needed, wasting energy. This paper proposes an architecture for managing A/V device power state with the key principle for each device to:

"wake up when it needs to, and go to sleep when it can".

This should enable power control to be more automatic and reliable, and provide greater usability to people as well as saving energy. The rest of this paper is organized as follows. First, key concepts for A/V systems are defined and explained. Then, the candidate architecture is proposed and detailed operational issues considered. Finally, there is consideration of the transition period with many legacy devices and a summary of next steps.

Audio/Video Systems

An A/V system is a collection of devices that provides video content (usually on a television), and/or audio content (usually on loudspeakers). Most A/V systems are found in residences, but they are present in all building types, including vehicles. Many A/V systems interact with devices in other locations via the Internet or in subscription television (cable/satellite) infrastructure. These remote devices are not part of the local A/V system. Information Technology (IT) devices like computers are increasingly connected to A/V systems, and to be compatible, including for power control, they need to implement the same A/V protocols and behaviors.

Typical residential A/V systems fall into two categories. In a simple system, there is no separate A/V receiver, so that all audio comes from the TV itself. Complex systems have a receiver which provides multi-channel sound and is used to select among the various sources (and can be a source itself). These systems commonly included Ethernet, Wi-Fi, HDMI, Audio, Composite video, and pay-TV connections. Many devices sold today already have some power management capabilities. For example, many subwoofers will go to sleep automatically if the audio input is silent for an extended period of time, and then wake when the audio reappears. Many A/V devices have an auto power-down feature that initiates after an extended time with no user input, but these typically lack a corresponding wake-up feature.

Concepts

The basic unit of an A/V system is a device, which has its own power state. Each device has a set of interfaces for communication. Connected interfaces on two devices form a link. The primary data transmitted across these links are streams of audio or video content. Devices can be the source (e.g. DVD player) or sink (e.g. TV or speaker) of a stream, or an intermediate device through which the stream passes that is not its source or sink. A component often ignored in considerations of A/V systems is the experience of the users who actually consume the content or otherwise interact with the devices. Data communicated other than the content streams includes control signals. Details of each of these concepts are covered below. Figure 1 shows how basic A/V devices map into the source, sink, and intermediate concepts. Figure 2 presents an abstract representation of the same thing.

Devices

Each device is individually powered, and have one or many communications interfaces, usually of a variety of technologies (see *Interfaces and Links* below), and has its own power state.

Power States

The overall power state of a device determines the types of functionality it is capable of, its responsiveness to the various interfaces it supports, its front panel user interface, and its power consumption. While the power levels of a device within a basic power state do vary somewhat, the basic power state is the primary determinant of overall energy use, and so the key consideration for saving energy in A/V devices.

Originally, A/V devices had only two basic power states: on and off. Decades later, two factors emerged to change this. First, the label “standby” was applied to any low-power state in which power consumption was non-zero, and as devices increasingly had off modes with non-zero power, standby became a synonym for off. Second, remote controls (usually with one-way infrared communication) were introduced which included the ability to turn a device on and off. When such devices were functionally off, they still required power to detect a power command from the remote control, creating a difference from the traditional off state. Such devices still had only two widely used power states, with disconnection from their power source occurring only rarely, and the “standby” state only exited with a power command and so still an off mode.

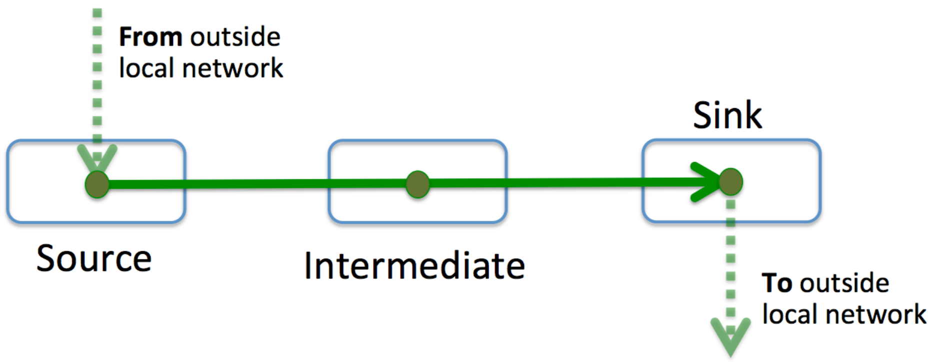
Some newer devices have three basic power states. An active mode, an off mode (which can only be exited with a power command), and an intermediate mode in which it is also responsive to communication from other devices. With Information Technology (IT) devices, these are usually called sleep states, but in A/V devices, no consistent terminology has been applied.

Interfaces and Links

An interface is hardware that enables a possible communications connection (link) to another device. Interfaces can be of many different wired technologies (e.g. composite video, line level audio, HDMI, or Ethernet) or, more recently, wireless.

Figure 1. Basic stream structure and typical components

Figure 2. Abstract stream structure (links to outside local network optional)



A data link is a point-to-point connection between two devices. There are many types: analog or digital, one-way or two-way, etc. A link is defined by the interfaces at each end, which must match. Originally, all A/V communication occurred in discrete links between two devices. HDMI introduced sequences of links of up to four devices. Network technologies enable arbitrary communication among any number of devices. Networks are not traditional in A/V systems, though as Internet Protocol technologies make inroads, they are beginning to be a factor.

Streams

A stream is an ongoing flow of data that transports audio and/or video content. It flows from a source to a sink, across one more links, of the same or different technologies. It is an association between the source and sink devices, and the source context (e.g. channel, time in media, or playlist name).

Some A/V systems can have multiple streams operating at the same time. Examples are when one source is being recorded and a second source is displayed on a TV, and “picture-in-picture” features that show two streams on the same screen. Stream topologies are becoming more complicated with ability to replicate video content to a second TV, and split off audio from a video stream to a separate device.

A stream may contain typical TV or movie content, or a content navigation screen. Streams can also be static (e.g. when content is paused), audio-only, or audio with peripheral video content (e.g. artist and song title).

Sources

A source is the initial appearance of a stream within an A/V system. Examples include local static media (e.g. DVDs), recorded media (on DVRs), remote content (e.g. from broadcast or service providers), or locally created content (from security cameras, PCs, or game consoles).

Sinks

A sink is the final destination of a stream, with the most common sink a television display with integrated speakers. A “display” communicates media to a user. A TV’s main component is its visual display; speakers are “audio displays”.

Intermediate Device

Some devices are sometimes or always only a "pass-through" of content and neither a source nor a sink. An A/V receiver is the most common example of this. Some devices can be sources, intermediates, or sinks at different times or for different purposes.

Control Signals

Control signals are data not part of a media stream itself, but which actively determine or describe the content being displayed. Examples include infrared data from remote controls, and control paths on digital links such as HDMI. High-end A/V components sometimes include interfaces for control signals, some of which use RS-232 interfaces; these enable a central controller to direct the detailed operation of other devices.

Power Control in Current Systems

Today's A/V systems are generally very good at accomplishing their primary function of displaying media content for people to enjoy. However, control of power states on these devices is frequently cumbersome and/or confusing. For a variety of reasons, devices are often left fully on when not needed, wasting energy. Users are annoyed and distracted by manually powering up devices when needed.

The core issue this paper addresses is the matching of content wanted (and actually consumed) by people, with devices being active as necessary to deliver that content. Energy efficiency is best served by doing this as precisely as possible, with the least burden imposed on users.

An Improved A/V Architecture

This section describes principles for a new A/V power control architecture, which builds on existing technologies, but makes key changes and additions. The core concept only addresses how devices should behave in an optimal future with all new devices; how we manage the transition is considered later. Power control is primarily about transitions – how a device knows when its state should change. This section covers principles fundamental to the new approach, issues in changing power state, what this means for how devices behave, and user interface concerns.

Creating this new architecture is part of an ongoing project; earlier phases [2] reviewed characteristics and features relevant to power control, first of current A/V devices [3], and then for communications technologies [4]. The most recent phase [5] explored how the concept of sleeping streams would affect the operation of devices and protocols, by assessing use cases for device and stream operation, resulting needed device behaviors, and particular issues that require special attention.

Technology architectures cannot be proved to be optimal nor can they be derived from data in the way that many physical principles can be. Rather, they can simply be described and explored, as well as compared to other technologies for their capabilities and burdens (such as complexity). An alternative architecture to the sleeping stream one would include a central control device that would manage the power state of all A/V devices in a local network. This approach appears to be more costly, less effective, and more likely to fail than the sleeping stream approach. One could require that all devices participate in a single network protocol. This is unlikely, at least for the foreseeable future, and in comparison to the sleeping stream model, seems unnecessary. Thus, this scheme is proposed as the best solution to the problem, though alternatives are welcomed to test this hypothesis.

Starting Principles

This project did not arise in isolation; rather, it builds on lessons learned over the last several decades in how to manage digital devices in a network context. A/V devices are beginning to adopt many conventions and technologies from computers in how they communicate and behave. Examples include the change from using only data links, to increasingly making use of network connections (that are digital and bidirectional), and the ability of some A/V devices to perform multiple tasks simultaneously. Thus, lessons from how PCs are power-managed are likely to apply to A/V devices. Key among these are:

- Use a three-state power state model (not two) and make it clear in the user interface.
- Maintain network connectivity in sleep.
- Ensure that power management is as automatic as possible.
- Keep delays on device wakeup short (a few seconds at most).

These lead to several conclusions about devices; they should:

- Be aware of the power state of other A/V devices in the local network.
- Be aware of the functional state of other A/V devices in the local network.
- Mostly toggle between on and sleep.
- Be quick to wake, and (relatively) slow to go to sleep.

In constructing the use cases for this project (see below), a design principle was that users care most that devices are on and available when they are wanted so that it is important to minimize or avoid forcing people to power up devices manually (e.g. with its remote control, its power switch, or with a different remote programmed to do so). Devices need to always wake if they need to (or even just might need to), to maximize user convenience and match expectations. If they fail to do this, users will likely disable power saving features leading to much energy waste.

Most people value convenience and a system of powering-down devices that is automatic, and an automatic system will engage considerably more often than manual-based ones will.

These principles, and consideration of how people do today, and will in the future, use A/V devices led to the sleeping stream concept and associated content.

Analysis

This project phase began with an assessment of abstracted use cases of device operation that affect power states in the context of sleeping streams. There is a minimum set of use cases that covers the needed complexity, and beyond this, additional cases only raise issues already covered by the basic set. For example, cases with more than three devices simply have several intermediate devices, each of which has the behaviors of the intermediate in the three-device case, so that no cases with more than three devices are needed. Table 1 shows an example use case with two devices and one content stream. The START and END lines show the power state of each device, while the intermediate lines show the sequence of actions taken by individual entities. If the TV had already been on at the start of the process, the resulting sequence would be effectively the same, since waking the stream would not require step 3 to wake the TV but would be otherwise identical. This is an example of an alternate use case that would add no new device behaviors.

Table 1 refers to a “fixed” stream. This is a content stream of finite duration, such as a movie. Other streams, such as broadcast media, are continuous and have no definite limit. Device behaviors will sometimes differ between these two stream types. The study [5] presented five one-device use cases, nine two-device cases, and two three-device cases. It also considered two cases in which the stream was addressed directly, rather than one of the devices, as well as two example cases of “failure” when a device does not behave as intended and so the resulting action is compromised. It is abnormal cases such as those that include failure that can create the most complexity for manufacturers and the most difficulty for users, so it is helpful when the core technology is as simple as possible.

Table 1. Use case example: DVD player powers up

Step	DVD	TV	Stream	Comments
START	Sleep	Sleep	Sleep	
				DVD power-up command (manual or internal timer) or manual play command
1	Wake			
2			Wake	DVD wakes up last stream it participated in
3		Wake		Stream involves TV so TV must power up
4		Input		Change Input (If necessary)
5	Play		On	Only after both devices fully wake (only applies to fixed streams)
END	On	On	On	

Note that this architecture does not specify the mechanisms by which the communication occurs that enables these sequences of actions to occur – just the result. Other standards — extensions to existing ones — provide the mechanisms.

In addition to device (and stream) power states and actions that entities engage in, the use cases also contain other elements. One is user action, which can be direct (e.g. use of a remote control), or indirect (e.g. change of state in an occupancy sensor). Another is a delay timer, such as a period of time of no activity that might initiate a power-down sequence, or the length of time that a warning is displayed of an imminent power-down. A third type of action is unexpected failures of a device or communications link.

The use cases outlined were evaluated to identify standard behaviors that devices should implement. Table 2 shows a portion of the result – behaviors that a source device must have. There are corresponding tables for sinks, intermediates, streams, and failure modes. While the use cases in the full report [5] on first glance suggest significant complexity, the behaviors show that in fact the system is based on a modest number of rules. The relative simplicity of the system is good for the design of communication protocols needed to accomplish it, the design of products which implement the protocols and behaviors, and for the ordinary human beings who must use the resulting products and systems.

Table 2. Source Behaviors

On

Notified stream to go to sleep
- Pause stream if fixed
- Go to sleep

Source paused
- Wait for X time
- Tell stream to sleep

Fixed Streams only

Fixed content ends
- Menu for X time
- Tell stream to sleep

“All devices ready" signal from stream
- Play content

Sleep

Powered up
- Wake self
- Wake stream

In the course of the analysis, it became clear that several temporary transitional states were needed for such a system to work. Figure 3 shows a proposal for how the three basic stream states and three transitional states might relate to each other; “GTS” is going-to-sleep. Devices commonly have transitional states internally but the system architecture may not need to represent them externally in the way that it needs to be cognizant of detailed stream states.

Content streams today are usually simple, involving no more than three devices all arranged in a linear fashion. However, it is quite possible, and even likely, that future streams will include branches into or out of the core stream as well as being longer than three devices. Figure 4 shows this graphically, but it is not apparent that such complexity needs to change the basic operation of streams sleeping and waking, except for how failure modes are treated.

Figure 3. State diagram for stable and transitional stream states.

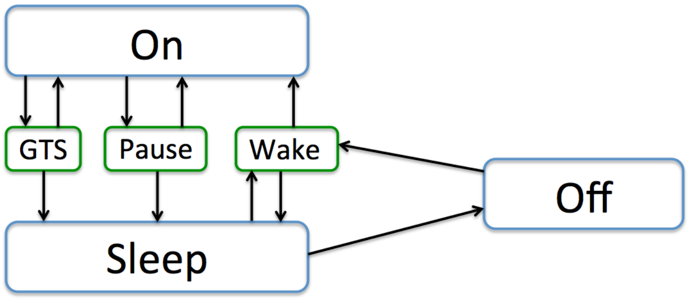
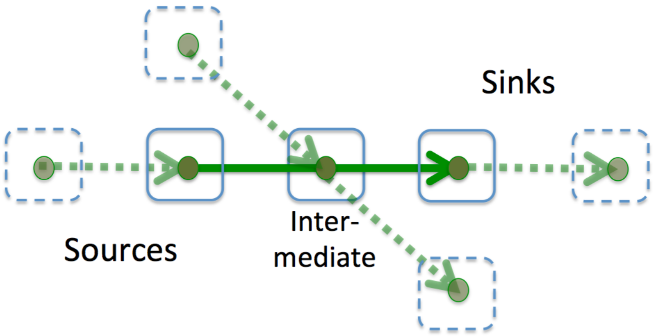


Figure 4. More complex stream topologies



Sleeping Streams

Media content streams are the core of A/V system functionality and need to evolve to create new capabilities and to optimally support power control. Computers have three basic power states, and since applications are contained within a single device, they go to sleep with the device, and the operating system informs applications when sleep and wake events happen. In A/V devices, streams are the analog of applications, being the basic unit of activity. Since streams inherently involve multiple devices, power management of streams can be considered separately from the power state of the involved devices (that is, while stream state influences device state and vice-versa, they are often not the same). In general, the three-state model has advantages over its two-state counterpart.

A "sleeping" stream has its representation maintained within devices and networks, but no media content is communicated. This enables new functionality to more easily match the power and functional state of devices to what is desired by the user. A sleeping stream is more available than a stream which does not exist. Creation of a new stream requires a series of link and inter-device negotiation steps, requiring time and user effort. In contrast, waking a sleeping stream requires many fewer steps. A sleeping stream is distinct from one which is active but just paused, since a paused stream needs to be able to resume with no delay at all and should always contain a static image of the pause point. Pausing usually is for only seconds or minutes. Sleeping can extend for months or years. While a device can be turned off then turned back on again, the alternative to a stream being on or asleep is for it to be deleted. Once deleted, it must be recreated from scratch for it to exist again.

As with sleeping devices, people will need to be aware of the sleep state of a stream to understand its functionality, as it may be useful in how devices are used. For example, the video stream from a security camera could be set as a sleeping stream and so have authority/capability to wake up a specific television (or group of displays) when it becomes active. By contrast, a mobile phone entering a space that does not have a relationship with the TV might need to have the TV powered up first before it can negotiate access to the display.

Another relevant analogy for streams in a network context is the Transmission Control Protocol (TCP), widely used in Internet communications [6]. It enables reliable bidirectional data transfer between two end points. Before any data can be transferred, a negotiation takes place between the two end points to agree to open the data connections, and the device that gets the request from the other can refuse it. Either side can close the connection at any time. TCP connections do not have the concept of a sleep state (although they probably should), but if an extended period of time passes with no data being sent, then either device can send a "keep-alive" packet with no stream data to assure the other side that it is still there. Since TCP includes acknowledgment packets, presence of both devices on the network is confirmed any time data or keep-alives are exchanged. The energy burden of occasional packets is minor, so long as doing this does not require a higher device power state. Thus, the existence of a potential flow of data is decoupled from the actual flow of data.

As the use case and behavior analysis showed, the combination of sleeping devices and sleeping streams provides needed flexibility for a variety of current and emerging usage scenarios while keeping the complexity of the system manageable for both devices and the people that use them.

An attribute of the sleeping stream concept is that when a new stream is to be created, all of the involved devices must be fully awake. This makes the complexity that a sleeping device must implement much less than otherwise. For example, security and authentication present significant challenges and these only are dealt with by devices that are fully on.

User Interfaces

Past experience with power control of electronics has shown that unclear or inconsistent user interfaces are a barrier to saving energy. In addition, standardizing user interfaces has a very low to no manufacturing cost, and improves the overall user experience. One need is to clearly embody the 3-state power model into A/V devices, in hardware (including indicator lights), and software controls [7,8]. Another need is to ensure that user interfaces for device control include device power state information, so that when devices available are presented, there are subtle distinctions made between those that are fully on and those that are asleep (off devices will generally not be visible at all). This distinction can help alert users when there are functionality differences between sleeping and on devices. It can also help a user to diagnose problems, e.g. to see when devices are fully on that don't need to be (many users do not commonly look at most devices, having them in cabinets, closets, or elsewhere).

Inertia is a powerful force in user interface design, and power control is not a feature that is likely to be a driver of purchase decisions, so manufacturers have little incentive to focus on it. However, it is clear that the energy savings benefits from improved user interfaces is orders of magnitude larger than the costs required to deploy them.

A further user interface challenge is how to represent content streams other than those actively being viewed. It remains to be seen what overall principles and approaches manufacturers will bring to this so it is premature to comment on it from the energy perspective. However, a clear visual distinction between streams that are on or asleep is needed, and this can be standardized once it becomes clear what that is (a possible approach is to dim or 'grey-out' a textual or iconic representation of a sleeping stream).

Other Considerations

In the analysis, we considered a variety of issues that the architecture, protocols, and devices must cover. The following are the major issues considered; full detail in the main project report [5].

Named streams. For device-device communication as well as device-human communication, streams will need to be distinguished from each other, which requires some mechanism for identification. The simplest way to do this is with a human-readable name. Such names will need to be unique within a local network.

Occupancy. As the purpose of audio/video streams is to communicate information to people, the occupancy of a person or people in a space can be critical information to know when to begin or end displaying a stream. Mechanisms to acquire and distribute occupancy information among devices will be a key technology innovation. This can also be extended to other uses of energy such as lighting and climate control.

Failures. When a device or communications link fails, the interaction between people and devices can be the most intense and important. Thus, how devices respond to failure conditions is critical to their user amenity and ultimately energy savings.

Multiple streams in a network. Local networks may contain multiple simultaneously active content streams, with some devices involved in more than one.

Multiple streams per device. While today collections of A/V devices usually only involve a single content stream at one time, in future many of these will be capable of, and commonly implement, more than one simultaneously. This will require adaptations to technologies, products, and user experience.

Multiple sinks and/or sources. Streams today usually involve a single source device and a single sink (an exception is when an A/V receiver sends audio to speakers independently of the video signal sent to a TV). As the availability of sources expands, we can expect more ability to merge multiple sources into a single stream. In addition, as the cost of displays drops, and the ability to direct data to multiple displays increases, it will be attractive for people in homes (and other use contexts) to replicate a content stream across multiple displays. Both of these will require the same sorts of changes that multiple simultaneous streams do.

Creating and maintaining streams. With persistent existence, there will necessarily be some overhead for both people and devices in managing streams. The burden of this needs to be kept as low as possible while providing needed capability and flexibility.

Emergency broadcasts. As content streams become networked, the possibility of using them for disaster notifications (natural and otherwise) will become apparent and implemented. This will require specific network availability of devices, authentication needs, and user preferences for this purpose.

The Transition

Even when a well-functioning system is implemented in all new devices, we will still have a huge stock of existing “legacy” devices that the new devices will need to interoperate with. Systems with legacy devices will use more energy and lack usability advantages; effort will be needed to assure that problems in both areas are minimized. New devices will need to detect when they are interacting with legacy devices and so adjust their behaviors. Some existing technologies have command/control mechanisms useful here. A new device could use these to manage the power state of legacy devices it is connected to. New devices could also provide user direction to manually manage legacy device power state when no other mechanism is available.

Next Steps

This architecture described here is being presented to the consumer electronics industry for consideration. If accepted, existing protocol standards will require extensions, in particular, adopting the three-state power model for devices and streams, and always exposing power and functional state to other devices on the local network. If accepted, the following steps are anticipated to result in products that implement it.

- Create a standard that describes the overall scheme of sleeping streams and associated details that could be forwarded to standards organizations for consideration. This should enable product designers to understand what to do and why, how to present this to users, and how to adapt the system to new circumstances.

- Review communication technologies to determine gaps between what they do today and what the architecture describes.
- Fill those gaps by amending technology standards.
- Put the technology into new products. Some features can be put into products even before the standards development is finished.
- Create a detailed summary of recommendations for how to deal with legacy products.

Critical to the process will be to get critical review from manufacturers of A/V devices, and the standards committees for relevant interface technologies. If a critical mass of these individuals and organizations do not support the system, it will not succeed. Manufacturers need to be assured that user amenity is the top priority.

For communications standards, the principal one needed to accomplish this in use today is HDMI [9]. Apart from providing the needed data path to send video data, HDMI also has features for content protection, addressing piracy concerns for many companies. HDMI is most commonly understood as a point-to-point mechanism, but it does facilitate a tree of devices with a single display at its root. It is possible to directly embed the notion of a sleeping stream within the core HDMI protocol, or implement it at a "higher layer" over the Ethernet channel present in newer versions of the standard. The UPnP protocol may also be critical.

It is also likely that one or more standards will get wide use for transporting A/V streams over Ethernet and Wi-Fi. These standards will also need to implement sleeping streams.

Considerations for Energy Policy

Energy policy can advance this technology in time and could make a difference in it being created at all. Past examples have shown that the Energy Star program has done this for communications technologies, and the nature of information technology suggests that this will be more possible and needed in future.

Many energy policy programs have a goal to be "technology neutral" to not favor or require technologies that may unfairly advantage specific companies. This is sometimes extended to not wanting to require network interoperability technologies. This is a mistaken application of the technology neutrality principle, as open standards do not favor specific companies but are rather available to any company. In addition, some energy savings opportunities are only available if companies implement specific technologies so that failure to embrace them forecloses some potential savings.

Conclusions

A/V device control is a complex topic with diverse devices, interfaces, technologies, system construction, and usage models. As power control has not been a high priority for the industries involved, it is not surprising that it is not well articulated in current technologies and devices systems. Digital technologies not only bring functionalities not available previously, but also offer the possibility of a more robust system for power control. A new power control architecture seems possible to construct and implement in technologies and products. The bigger challenge will be to improve products in the interim that have some legacy analog interfaces which inherently complicate power control.

Acknowledgement

This work was supported by the California Energy Commission's Public Interest Energy Research program and by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy under Contract No. DEAC02-05CH11231.

Many thanks to Gari Kloss for her invaluable contributions.

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What is an energy efficient TV? Trying to find the best TV in China and in Europe

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Abstract

Topten International launched a test project in order to find out whether there are large differences in energy efficiency between the TVs on the Chinese and the European market. For the test, the most energy efficient 46-inch TV models were selected from the lists of Topten Europe and Topten China. The TVs were tested and classified according to the Energy Labels and standards of Europe and China by three participating testing institutes. Apart from verifying the declarations and compliance with minimum efficiency requirements the main results support the initial theses: the On mode power of the European TV model is considerably lower than that of the Chinese model. The question which of the two TVs is more efficient however is not easy to answer: according to the European Union (EU) Energy Label, the EU TV is the more efficient of the two test TVs. On the Chinese Energy Label however, the Chinese TV reaches a better efficiency grade than the EU TV. Different efficiency definitions on the two Energy Labels make this possible: while an efficient TV in Europe is one with low power in On mode compared to a reference model of the same screen size, an efficient TV in China is bright relative to its power.

The results show that details of policy instruments can strongly influence product design. These instruments must therefore be carefully defined in line with their primary aim. The present project allows identifying aspects of the applied Labels and standards that could be improved.

Background

Topten[1] is an international program designed to create a dynamic benchmark for the most energy efficient products [1]. It addresses consumer's needs, but also manufacturers, retailers, researchers and policy makers to push them to produce more energy efficient products. There are currently 20 national Topten sites throughout Europe, China and the USA. Each site provides information on the most energy efficient products available in their local markets.

Toptens goal is to contribute their expertise to the worldwide distribution of the most energy efficient technologies. Due to different measurement standards and efficiency assessments in many countries is difficult to compare the Best Available Technology (BAT) from one region to another. This is also the main limitation to the benchmarking document on TVs from the 4E project [2], which found that the average Energy Efficiency Index in the countries considered improved by 8% from 2008 to 2009. Its global presence allows Topten to closely look at some products from different regions and compare their efficiency levels [3].

A comparison of the energy consumption of TV models on Topten websites in China, Europe and USA, based on declared power values, showed that Chinese TVs have a higher energy consumption than European and American models [4] (figure 1).

[1] www.topten.info

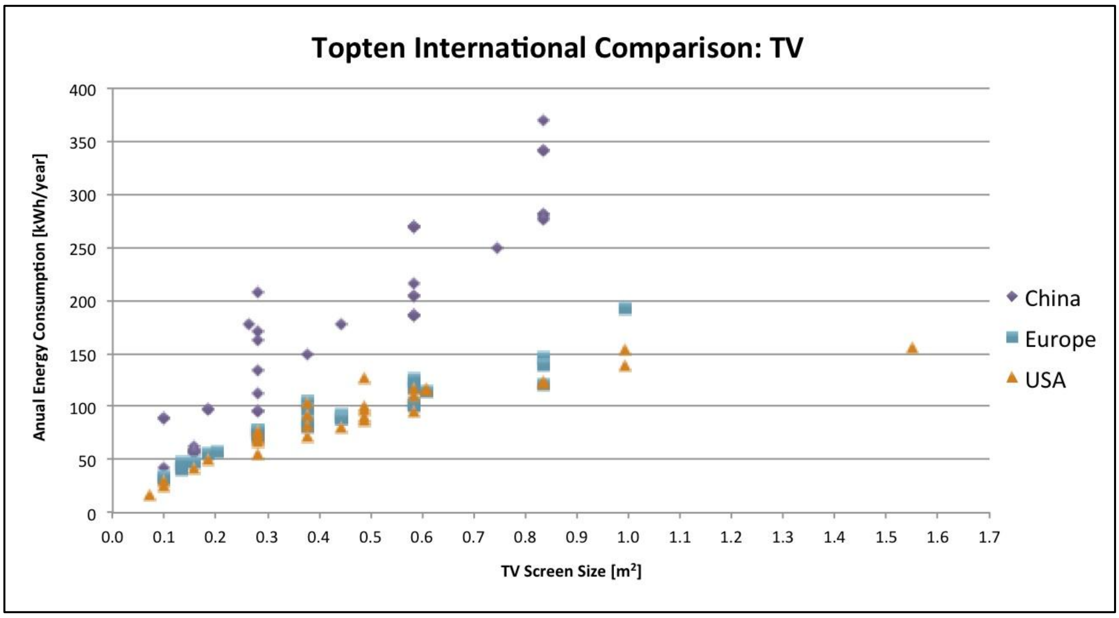

Figure 1: Annual Energy Consumption of Topten TVs

Source: [4]

Topten International wanted to look closer at the reasons for this finding: is it a fact that Chinese TVs are less energy efficient than European (and US-American) TVs? Or do different measurement standards lead to a higher power declaration in China? Topten International launched the testing project, which allows to better understand the details of the Chinese and the EU energy labels for TVs, and the measurement methods they are based on. The results are also used to verify the declared power and consumption values, and to determine the current level of the most efficient TVs on the market.

Also the Superefficient Equipment and Appliance Deployment (SEAD) Initiative[2] aims at determining the most efficient TVs of the world. Their results [6] are compared with the findings of the Topten test project in the final section.

Part of the project's findings have also been presented in [5] at eceee.

Methodology

The most energy efficient 46-inch TV models on the Chinese and European markets were both purchased and tested according to the Chinese and the European Energy Label and the relevant measurement standards by three participating testing institutes.

Product selection

The following requirements were defined, so that the two TV models do not provide different functionalities, which would make them not comparable:

- Screen diagonal: 46 inch / 117cm
- Resolution: 1920 x 1080
- No hard disk integration
- Automatic brightness function (or similar function) that can be switched off manually

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[2] www.superefficient.org

At the end of June 2012 the TV models from the Topten China and Topten Europe lists with the lowest On mode power consumption - conforming to the above specifications - were selected for the test (figure 2). The technical specifications as declared by the manufacturers are presented in table 1.

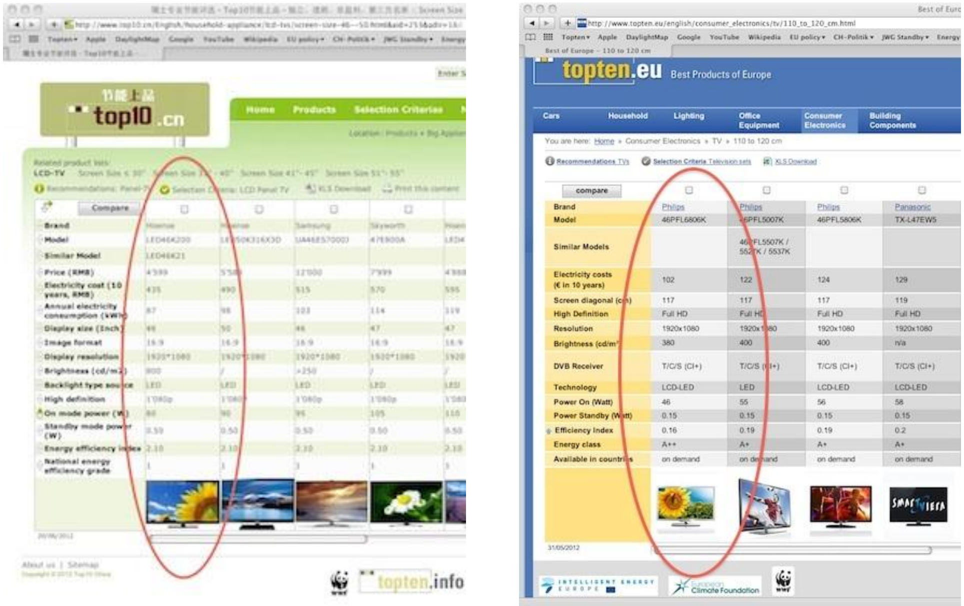


Figure 2: Topten China and Topten EU product lists with the selected TV models (June 2012)

Table 1: Selected TV models and technical specifications

Declarations according to	**Chinese Energy Label**	**European Energy Label**
Brand	Hisense	Philips
Model	LED46K200	46PFL6806K
Technology	LED-LCD	LED-LCD
Diagonale (Inches)	46	46
Resolution (Pixel)	1920x1080	1929x1080
On mode power (W)	80	46
Standby power (W)	0.5	0.15
Annual electricity consumption (kWh/year)	87	63
Energy Efficiency Index EEI	2.10	0.16
Energy label grade / class	1	A++

Product testing

Both TVs were tested by the three participating test institutes: CVC (Gunangzhou, China), NIM (Beijing, China) and VDE (Offenbach, Germany), according to the Chinese and the European measurement standards relevant for the respective Energy Labels and rated according to the Labels.

The Chinese and European Energy Labels for TVs

Figure 3: Chinese and European Energy Label for TVs

The Chinese Energy Label rates the TVs from grade 3 (least efficient) to 1 (most efficient). The grade 3 limit corresponds to the minimum energy performance standard (MEPS). For plasma TVs this is higher (less efficient) than for LCD TVs [7]. The European Energy Label ranges from A to G [8], even though TVs less efficient than class D are banned from the market [9]. TVs reaching better classes (A+ or A++) feature a label including these classes. From 2014 the scale will be A+ to F for all TVs [8].

The two Energy Labels are based on different definitions of TV efficiency: While in Europe an efficient TV is one with low power in On mode compared to the power of a reference model of the same screen size (P/P(dm^2)) [8], in China the most efficient TV is the one that is brightest relative to its power (high cd/W relation) [7]. European TVs are prevented from reaching low power simply by being very dark: the brightness in factory settings (this is how the TVs are measured) must be at least 65% of the maximum brightness.

According to both Energy Labels larger TVs can have higher power without getting a worse classification (EU: because larger reference TVs also have a higher power input; CN: because a larger TV has a higher luminous intensity ($Cd = Cd/m^2 * m^2$)). In Europe brighter TVs must be more efficient than darker ones in order to get an equal classification, while in China, in addition to larger TVs, brighter TVs can have a higher power without getting 'punished' with a bad grade.

The measurement of the On mode power consumption is based on the dynamic broadcast content of the IEC 62087 standard [10] for both energy labels, and both consider the average On mode power consumption over 10 minutes. However, the settings that are chosen for the On mode power and the luminance measurements are different for the two standards:

- Chinese energy label: brightness and contrast settings are adjusted to a 8-greylevel-signal, other image settings are set to 'factory setting'; Automatic Brightness Control (ABC) is switched off.
- EU energy label: factory settings ('out of the box'). ABC is switched off.

Apart from the different brightness and contrast settings, different signal input terminals are used (GB 24850: Rundfunk (RF, aerial broadcast); EU: High Definition Multimedia Interface (HDMI)) and different voltages are applied: 220V are used for the Chinese energy label, 230V for the EU energy label measurements.

Relevant regulations and standards

China: GB 24850: 2010 *Minimum allowable values of energy efficiency and energy efficiency grades for flat panel televisions* [7]. This paper contains the legal minimum efficiency requirements, the Energy Label details for TVs as well as the EEI calculation formulas and the measurement procedure. It is therefore referred to as 'standard' (as in Chinese). The standard refers to the dynamic broadcast content of the IEC 62087:2008 [8] for the measurement of the On mode power. GB 24850 also includes a method for measuring the luminance and the Standby power of the TV.

Europe: *EU regulation No 1062/2010 on energy labelling of TVs* [8]. For the measurement of the On mode power IEC 62087: 2011 Methods of measurement for the power consumption of audio, video and related equipment [10] is applied (as recommended in a separate Communication [11]). For the Standby measurement [11] refers to the standard for measurement of low power consumption [12]. The EEI calculation formula and the labeling scale are contained in [8].

Results

Energy Efficiency Index (EEI) and Energy Class / Energy Grade

Table 2: Main results according to the EU Energy labelling regulation

EU Energy Label – 1062/2010						
	Philips 46PFL6806K			**Hisense LED46K200**		
Institute	**EEI**	**Class***	**Luminance ratio**	**EEI**	**Class**	**Luminance ratio**
CVC	0.161	A+	55%	0.302	B	54%
NIM	0.163	A+	53%	0.302	B	99%
VDE	0.169	A+	62%	0.301	B	99%

*Including the justified 5% On mode power reduction for the ABC to calculate the EEI, the results confirm the declared A++ class of the Philips TV.

<u>All test institutes report the Philips 46PFL6806K to be of higher efficiency than the Hisense LED46K200 when measured and classified according to the European energy label</u>. The institutes' results on EEI and efficiency class are in line, for the luminance ratio the institutes however reach different results.

For the Philips model all institutes calculated an EEI slightly above 0.16 and thus reported an energy class A+ for the Philips TV – while Philips declared it to be in class A++. According to the Labelling regulation, TVs which have the ABC activated receive a 5% reduction on the measured On mode power for the calculation of the EEI. The test institutes did not consider the 5% reduction, even though the Philips TV does have its ABC enabled at factory settings. When considering the 5% reduction, the declared A++ class of the TV can be confirmed (see table 5 for more details).

Table 3: Main results according to the Chinese energy labelling standard

Chinese Energy Label – GB 24850				
	Philips 46PFL6806K		**Hisense LED46K200**	
Institute	**EEI**	**Grade**	**EEI**	**Grade**
CVC	1.15 (1.34*)	2 (2*)	1.36 (1.50*)	2 (1*)
NIM	-	-	2.33	1
VDE	1.43*	1*	2.86*	1*

*Measured with HDMI input terminal, not RF as officially relevant for the Label

Contrary to the assessment of the European energy labelling regulation, <u>all test institutes report the Hisense LED46K200 to be of higher efficiency than the Philips 46PFL6806K when measured according to the Chinese standard.</u>

However, the three institutes reached different EEI results for both TV models, and even different energy grades on the Chinese Energy Label. (NIM did not report valid results for the test of the Philips TV according to the Chinese standard.)

Compliance check
Philips 46PFL6806K

Table 4: Compliance check for the Philips 46PFL6806K

Philips 46PFL6806K	On mode power (W)	Standby mode power (W)	Peak luminance ratio
Declared	45.5	0.15	65%
Incl. tolerance	48.7 (7%)	0.25 (0.1W)	60%
Result by CVC	44.25	0.12	55%
Result by NIM	44.59	0.16	53%
Result by VDE	46.11	0.12	62%
Compliance?	YES	YES	To be checked

The measurement tolerance for the On mode power of European TVs is 7%. The declared power of the Philips has been confirmed by the tests (table 4). The maximum allowed Standby power for TVs is 0.5W [9], the measurement tolerance is set at 0.1W. The Philips 46PFL6806K clearly meets this requirement. The brightness in factory settings or the home mode is required to be at least 65% of the maximum brightness. The institutes reached different results on the peak luminance ratio, but all are below 65%. How about the Energy Class? All institutes reported an A+ for the Philips TV instead of the declared A++. For the calculation of the EEI the institutes missed to include the 5% discount which is granted for TVs with an ABC: if the ABC is activated in the factory mode and the luminance of the TV is reduced at an ambient light intensity between 20 lux and 0 lux, the measured On mode power will be reduced for the calculation of the EEI and the annual energy consumption. This clause in [8] might not be obvious, and as the test reports show, it can easily be missed. Table 5 compares the relevant values with and without 5% ABC reduction.

Table 5: EEI calculation for the Philips model with reduction for ABC

Philips 46PFL6806K		CVC	NIM	VDE	Declared
without reduction	On mode power measured	44.3	44.6	46.1	45.5
	kWh/a	64.6	65.1	67.3	
	EEI	0.162	0.163	0.169	
	Class	A+	A+	A+	
with 5% reduction for enabled ABC	On mode power	42.0	42.4	43.8	43.2
	kWh/a	61.4	61.8	64.0	63.1
	EEI	0.154	0.155	0.161	0.159
	Class	A++	A++	A+	A++

The test institutes confirmed that the Philips TV has a light sensor with a brightness reduction function activated in the factory mode. Thus it deserves the 5% reduction. The On mode power measured by VDE is within the tolerance of 7% of the declared value. Therefore all results confirm the declared On mode power, EEI and Energy class of the Philips 46PFL6806K.

Hisense LED46K200

Also in China the maximum Standby power for TVs is 0.5W [7]. For the Hisense LED46K200 the declared standby power of 0.5W was confirmed by all three testing institutes (table 6). NIM and VDE also confirmed the declared grade 1 of the Hisense. CVC however reports an EEI of 1.36 (35% lower than what is declared) and grade 2.

Table 6: Compliance check for the Hisense LED46K200

Hisense LED46K200	Standby power	EEI	Grade
MEPS	0.5 W	0.6	3
Declared	0.5 W	2.1	1
Measured by CVC	0.42 W	1.36	2
Measured by NIM	0.35 W	2.33	1
Measured by VDE	0.41 W	2.86	1
Compliance?	YES	To be checked	

MEPS: Minimum Energy Performance Standard

Measured values

Standby power

The institutes' results for Standby power differ by up to 0.12W for the Hisense TV and 0.05W for the Philips TV (table 7). These deviations are larger than the measurement tolerance of the EU Ecodesign regulation of 0.01W [11]. The deviations between the institutes are larger than those between the two measurement standards, which are no more than 0.1W. The deviations between CVC and VDE are no higher than 0.02W (Hisense/EU).

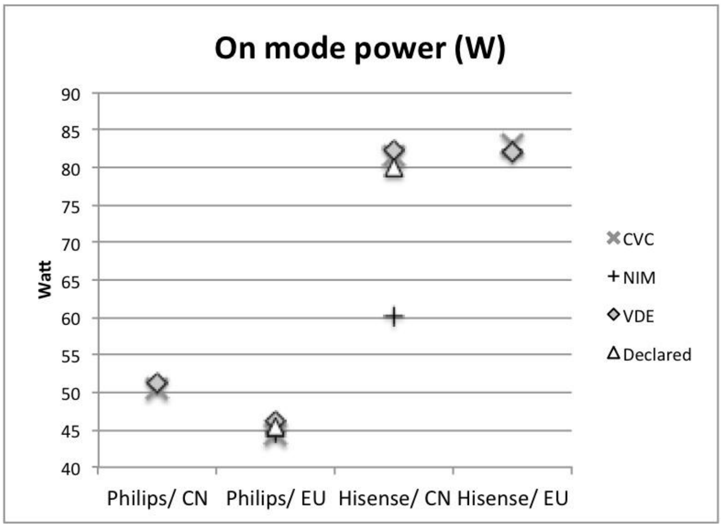
Table 7: Results of the Standby power measurements

Standby power (W)	Declared	CVC	NIM	VDE
Philips/ CN		0.11	0.16	0.12
Philips/ EU	0.15	0.12	0.16	0.12
Hisense/ CN	0.5	0.42	0.35	0.41
Hisense/ EU		0.43	0.35	0.41

CN: according to the [7], EU: according to [8]

On mode power

All institutes report the Hisense LED46K200 to have a higher On mode power than the Philips 46PFL6806K, for all measurements (figure 5). Results according to the EU labelling regulation are well aligned between the institutes, while for the measurement of the Hisense TV according to the Chinese standard NIM reports a lower value than the two other institutes.



On mode power (W)	Declared	CVC	NIM	VDE
Philips/ CN	-	50.44 (51.93*)	-	51.35*
Philips/ EU	45.5	44.25	44.59	46.11
Hisense/ CN	80	81.53 (82.28*)	60.11	82.32*
Hisense/ EU	-	82.93	82.28	81.93

Figure 5: of the On mode power results

*measured with HDMI input terminal instead of RF

On mode power measurements according to the EU standard:

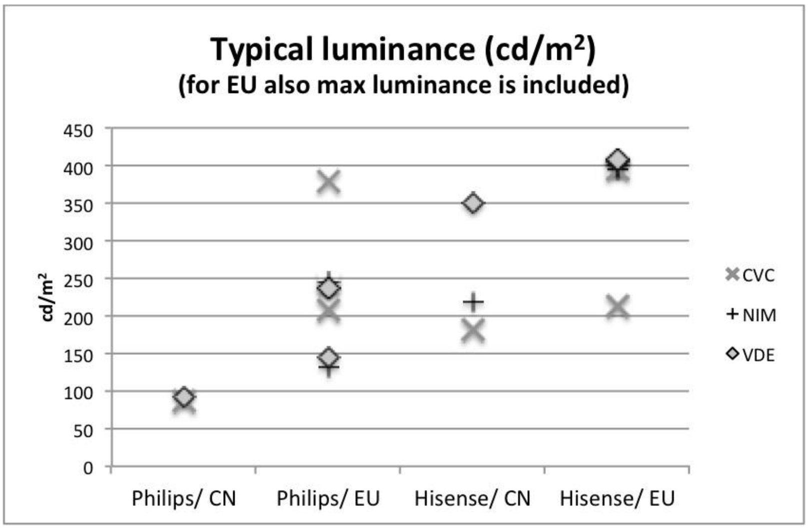
For the power measurements of the Philips according to the EU labelling regulation all institutes reached very similar results close to the declared 45.5W (despite different brightness settings and at different luminance levels, see below). The measured On mode power of the Chinese TV is around 80% higher than that of the EU TV.

On mode power measurement according to the Chinese standard:

CVC's and VDE's On mode power results for the Chinese TV according to the Chinese standard are close to the declared 80W; the deviation is below 3%. The result from NIM however is 25% lower. (For the luminance however CVC and NIM's results are closer to each other, while VDE measured at a much higher luminance – see below).

Also for the power measurement of the EU TV the results by VDE and CVC are very close (51W) (also the measured luminance does not differ too much, see below). NIM could not adjust the Philips model to the 8-greylevel-signal and did not report a valid result for this measurement. Also VDE reported problems to adjust the Philips TV to the 8-greylevel-signal of the Chinese standard, and finally chose the same settings as CVC. Using the HDMI input terminal instead of RF for the measurement by VDE does not seem to be leading to large differences in the results.

Luminance



Luminance (cd/m²)	Typical luminance			Max. Luminance (EU)		
	CVC	NIM	VDE	CVC	NIM	VDE
Philips/ CN	87.62 (87.77*)		92.93*			
Philips/ EU	207.5	131.36	146	380.2	245.54	237.2
Hisense/ CN	182.95 (183.44*)	219.64	351.23*			
Hisense/ EU	213.8	395.9	405.1	394.5	401.08	407.6

Figure 6: Results of the luminance measurements

*measured with HDMI input terminal instead of RF

Figure 6 shows that for both TVs the luminance is higher at factory settings (EU standard) than when adjusted according to the Chinese 8-greylevel-signal. So, many Chinese TVs are measured at lower brightness than they are delivered with. The detail brightness and contrast setting chosen by the institutes for the luminance (and power) measurement are displayed in table 8.

Table 8: Brightness and contrast settings chosen for the luminance measurements

			Brightness setting	Contrast setting	Luminance (cd/m^2)
GB 24850	CVC	Philips	37	100	87.6
		Hisense	50	78	183.0
	NIM	Philips	-		-
		Hisense	54	73	219.6
	VDE	Philips	37	100	92.9
		Hisense	50 (48*)	78 (48*)	351.2 (303.2*)
EU 1062/2010	CVC	Philips	37	100	207.5
		Hisense	45	76	213.8
	NIM	Philips	Factory settings		131.4
		Hisense	Factory settings		395.9
	VDE	Philips	50	75	146.0
		Hisense	50	50	405.1

*settings chosen by VDE's interpretation of the translated standard

Luminance measured according to the EU Energy Label:

The luminance should be measured at factory settings. Once the settings have been changed, they can be regained by selecting 'factory settings' in the menu. Still the brightness and contrast settings chosen by the institutes and the luminance measured differ (table 8).

In the case of the Philips TV, CVC measured a considerably higher luminance than VDE and NIM. NIM's detail settings are not known. When looking at the factory brightness and contrast settings reported by the two other institutes, the difference in the measured luminance cannot be explained.

For measuring the maximum luminance all menu settings should be set to achieve the brightest image that can be obtained. Again, VDE and NIM report similar results for the Philips TV, while CVC measured a much higher maximum luminance (figure 6). Coincidentally, the peak luminance ratios calculated by CVC and NIM (table 2) end up to be very similar, even though they are based on different values.

For the Hisense it is the other way round: CVC measured around half the luminance of the other institutes when the TV is in the factory settings (table 8). Again, the brightness and contrast settings by VDE and CVC differ, but do not provide an explanation for the different results, while information on the settings chosen by NIM is missing. The Hisense's maximum luminance results obtained by the institutes differ by only around 3% (figure 6).

Luminance measured according to the Chinese standard:

Especially for the Hisense TV, the luminance results the institutes reached according to the Chinese standard also differ. VDE had doubts about their settings and finally chose the settings according to CVC. While the luminance results by CVC and VDE with identical settings are similar for the Philips TV, VDE's luminance result for the Hisense is much higher. NIM chose similar settings for the Hisense, but reached a different result. NIM could not adjust the Philips TV model to the 8-greylevel signal. The other two institutes obtained very low luminance results between 87 and 93 cd/m^2 for the Philips TV (figure 6).

Interpretation and limitations

The results according to both standards and for both TVs seem to show little correlation between:

- the brightness settings chosen by the institutes and the luminance measured
- and the luminance measured and the On mode power.

In discussions with the institutes explanations for the deviations were sought.

Part of the background is, that principally there are two ways to change the brightness in LCD TVs: either by the LCD layer, which works as a shutter and varies the amount of light that can get through, or by changing the intensity of the backlight. The LCD layer has no effect on the power, but the brightness of the backlight does. The two tested TVs use different technologies: the Hisense TV, a relatively simple model, adjusts its brightness through the LCD layer, while the intensity of the backlight cannot be changed. Therefore the product always has the same power while in On mode, and, during the test by VDE, its power ranged from 81.8W to 82.4W only over the course of the dynamic broadcast content. The Philips TV on the other hand is more sophisticated: the 'dynamic backlight' setting leads to a lower power at dark scenes through dimming some LEDs of the backlight. Its power ranged from 37W to 57W during the test, depending on the brightness of the scenes. So, in the case of the Philips TV, a higher brightness can be associated with higher power, but is not necessarily so (when achieved uniquely by the LCD layer). The Philips also has an Automatic Brightness Control (ABC) adapting the brightness to the ambient light intensity, while the Hisense does not have such a function.

For the Hisense TV an explanation could not be found regarding the deviations between the institutes' test results. NIM's power result according to the Chinese standard (60W) cannot be explained. VDE could not achieve any modifications in On mode power in this model, and also CVC reports only values around 82W. The deviations between the luminance measured by the institutes according to the Chinese standard could partly be explained by the bad repeatability of the test. The Chinese institutes follow a methodology where several test engineers separately define the brightness settings according to the 8-greylevel-signal to obtain the best visibility, before discussing and agreeing on a certain procedure. CVC and NIM chose different settings, which could have lead to the different luminance results. Why VDE measured a higher brightness when choosing the settings according to CVC is not understood. Also not clear is why the institutes chose different 'factory' brightness and contrast settings for the measurement according to the EU standard, which may have lead to the lower luminance result CVC reports here.

In the case of the Philips model, the complexity of the product's setting possibilities offers some explanations for the different results obtained by the institutes. At first look it seems that the institutes did not choose identical brightness and contrast settings when measuring in the factory settings for the EU Energy Label– despite there being a 'factory settings' function in the menu. First it was found that the factory settings defined in the menu can be changed by software updates. Secondly, the 'factory settings' button in the Philips does not reset all possible settings: the 'colour temperature' for instance, which does influence the power by around 5% and the luminance by 30%, has to be reset manually.

Also different sound volume settings can have a faint influence on the power (Δ < 1W), and there is a contradiction between the EU Labelling regulation (asking for factory settings) and the IEC 62087, which defines a certain sound power level. Additionally, the ABC should be switched off for the test. CVC and NIM however both reported to have left the ABC on for the measurements according to the EU Energy Label, due to a misunderstanding. In the dark conditions of a test room, switching on the ABC can change the power by 15% and the luminance by 20%. It seems that when combining different setting options, the power and brightness differences of 5 to 20% can multiply and add up to around 30%. This can explain the luminance differences the institutes report for the EU Energy Label. The maximum luminance should be measured 'with the brightest picture which can be obtained by changing the menu settings'. This open formulation includes all menu settings affecting the brightness. But the very high maximum luminance CVC has reported could not be explained.

The Chinese Labelling Standard does not seem to be ready for TVs with complex menus as the Philips. The instruction as how to adjust the picture to the signal contains reference only to a few settings, such as 'contrast' and 'brightness'. It is not clear how to proceed with other settings affecting the brightness, e.g. the backlight.

Conclusions

The outcome shows three unambiguous results:

1. According to the EU Energy Label the most energy efficient European TV is more efficient than the best Chinese TV.

2. According to the Chinese Energy Label the most energy efficient Chinese TV is more efficient than the best European TV.

3. The Chinese TV has a higher On mode power than the European TV.

1 and 2 are possible because to the different definitions of ‘TV efficiency’ by the Chinese and the European Energy Labels: while in Europe an efficient TV is one that consumes little power relative to its screen size, the most efficient TV in China is the one that is brightest relative to its power.

The fact that the European TV performs better according to the EU Energy label, and the Chinese TV performs better according to the Chinese Energy Label shows that manufacturers adjust their products very much to the details of energy labels and standards; the energy label does have a strong influence on product design. The European Philips TV is even difficult to assess according to the Chinese standard (two of the institutes reported difficulties to adjust it according to the 8-greylevel-signal); the product was not designed to be measured with this standard. It is therefore crucial that an energy label (and other instruments such as MEPS) is well defined. If the label aims at saving energy, the label should indeed favour the most energy saving products by choosing an appropriate definition of energy efficiency. The measurement procedure should reflect real usage conditions and not leave room for interpretation.

The third result implies that the European Energy label does better when it comes to favouring energy saving TVs than the Chinese standard. The luminance results however also show that the European TV is darker than the Chinese TV for most of the measurements. The European standard favours dark factory settings (down to 60% of a – sometimes – low maximum brightness), which bears the risk that the brightness settings are tuned higher as soon as the product is installed at home and the effective energy consumption is higher than declared. Stiftung Warentest found that after improving the picture quality by changing the factory settings, the On mode power of (European) TVs could increase by 50% [13]. The Chinese standard on the other hand favours very bright TVs.

According to the EU standard, On mode power measurements deliver similar results, but the luminance results show bigger disparities. The differences in the results according to the Chinese standard are large - the results do not seem to be fully repeatable.

Comparison with SEAD results

SEAD awarded ‘most efficient TVs’ for four different regions of the world for three size ranges [6]. The two TV models tested in the present study were not among the awarded models. China was not a focus region of SEAD. In Europe and North America the awarded TV models were also on the Topten lists and are among the most efficient TVs. According to the Topten lists, which refer to regional or national standards and labels, the TVs awarded by SEAD are however not the most efficient models. A main reason for the different outcome can be the different selection methods: while Topten covers the entire market of interest, manufacturers had to apply for the SEAD award. TVs were tested for the SEAD award – for all regions according to the same measurement procedure. TVs that were awarded as efficient according to the SEAD method are not necessarily the most efficient TVs when assessed according to regional measurement standards and labels.

Main problems discovered in the standards

EU Energy Label

A major problem of the EU Energy Label for TVs is the staged introduction of the A+-classes, which is scheduled too late: in 2012, the best TVs already reached class A++ [14]. This class will however be displayed on all labels in 2017 only, and A+ in 2014 [7]. Before this, all TVs not reaching the A+ class feature labels where A is the top class – signalling to consumers that this is the BAT.

Another flaw is that the EEI and the energy class cannot be verified from the declared values. Apart from that, the minimum peak luminance ratio is not clearly defined. The standard favours dark factory settings with sometimes poor picture quality [13]. Consumers will in some cases have to change the settings to achieve a better picture and end up with a higher electricity consumption than declared. Other problematic aspects:

- The Pbasic for calculating the reference power depends on the number of tuners, but it is not clearly defined what an individual tuner is. The verification authorities from Germany and VDE assume that even a tuner which is capable of decoding DVB-T, -C and –S signals is only accounted for as more than one tuner if more than one of these can be used in parallel. The Energy Labelling regulation however does not specify this interpretation, neither does the accompanying guideline [15]. Therefore the EEI and the energy class cannot easily be verified.

- TVs that have an ABC and/or a function that automatically reduces the luminance below at least 20 lux activated in the factory settings receive a 5% discount on the measured On mode power for the EEI calculation. From the technical datasheet nobody can tell if this is true or not. This also complicates the verification of the declared EEI and the energy class.

  For the revised Ecodesign regulation even a 10% reduction is recommended [16] – with however appropriate measurement and requirements for an ABC (progressive reduction of screen illuminance below 300 lux).
- The EU Energy Label asks for measurements in the factory settings, but due to complex menus, these are not easy to retrieve once the settings have been changed. Also the detail factory settings in one model can change over time through software updates. Several changed settings can lead to differences in power and luminance of around 30%.
- The peak luminance ratio is problematic: the ecodesign regulation requires it to be 65% at least. In the very same document however it is stated that 60% is sufficient (including measurement tolerances). So manufacturers set the luminance at 60% of the peak luminance and declare it to be 65% - all conform. Moreover luminance values are not declared, and therefore cannot be checked.
- A total of seven different documents are needed to define or to verify the declaration and compliance of TVs. Most documents and standards are not clearly referred to and not clearly defined (IEC 62087 is recommended to be used for assessing the On mode power; in a different document, two standards for the luminance measurement are recommended). Without insider knowledge it is not possible to measure a TV according to the energy label.

Chinese standard

The main problems are the lack of declaration and the settings for both the power and luminance measurement based on the 8-greylevel-signal, which do not seem to be fully repeatable.

- Nothing needs to be publicly declared by the manufacturers: neither the calculated EEI, nor the On mode power or the luminance. Instead manufacturers declare certain EEI and standby power values along the grade limit or subsidy line. It is not possible to compare the products within one label grade regarding their energy efficiency.
- The picture settings for measuring the On mode power do not seem to be distinct. The standard does not specify if the picture quality also needs be changed with the ‘backlight’ setting.
- The settings for a measurement over the HDMI input terminal are not defined in the standard. Accordingly HDMI is by now a trend on the market, but RF is still dominating.
- Different values for the signal processing power Ps are subtracted from the measured On mode power value, depending on the input terminal: Ps=10W for analogue RF input, but 17W for digital RF input. Manufacturers can thus achieve the best results by choosing the most convenient input terminal (with the largest Ps). Ps for the HDMI input terminal is not defined. The formula in the new draft standard GB 24850-201X [17] does not contain any Ps or other value to be subtracted from the measured power any more.

Recommendations for a harmonised Energy Label and standard

- An energy label should aim at reducing energy consumption by guiding consumers to the products that consume the least energy while still providing their function. As the results of this project imply, energy labels also strongly act on manufacturers and influence product design. Therefore it is important that a label is designed to label those products with good grades or classes that really help to lower the energy consumption.
- The usual approach however is to allow a higher energy consumption for products which offer ‘more’ function (larger screen, brighter image, higher capacity or volume, etc.) [18], and

usually for larger products it is easier to obtain good grades. This leads consumers to choose larger or brighter products than needed based on the good energy class or grade – which do not fulfill consumers' expectations to save energy, but actually consume more energy than needed.

- In order to contribute to energy savings, energy labels should make the higher energy consumption by larger, brighter or stronger products visible instead of rewarding increased size, brightness or capacity: grade and class limits should consequently be defined based on a degressive or even capped approach. This requires larger products to be of higher efficiency in order to reach good grades than smaller products.
- As for the brightness settings, the European approach seems reasonable: to measure at factory settings influences the way the products are delivered or the 'home' mode. TVs should be measured in those settings the consumer is most likely to choose in order to reflect real usage conditions – and the factory settings are quite probable to be used also after installation, as long as these settings are not too dark. Since consumers can change the settings in any case, it is good to also tackle the maximum brightness. If this is much brighter than how the TVs are measured, the real energy consumption can be much higher than declared. The min. 65% of maximum brightness in delivery state requirement leads manufacturers to renounce on unnecessary high maximum brightness settings. The wish for a bright 'Shop' mode should guarantee a certain minimum brightness. Still, it cannot be excluded that dark factory settings are preset which have to be changed by consumers, who then end up with a higher electricity consumption than what is declared.
- The Chinese standard does the opposite: it favours bright (and large) TVs, which acts against the energy label's main aim to save energy. With an energy label similar to the European one, where higher brightness is not rewarded, manufacturers have to find a midway between too low (bad visibility in shops) and too high (bad energy grading) brightness.
- The measurement at factory mode seems to be clearer than at a predefined brightness (which has to be obtained first by changing the settings with a test pattern). The problem that the factory settings are difficult to retrieve and can change over time should be solved – e.g. with a requirement for an easy reset possibility of all parameters.
- A harmonised standard should define test patterns to be used for the brightness measurement, which is distinct and leaves no room to adapt settings. A measurement standard should include advice as how to change the settings in order to obtain the brightest image (including 'backlight' setting, colour temperature, contrast etc.).
- ABC should be considered in an appropriate way (a discount that reflects the energy savings that are indeed achieved at real usage conditions).
- The relevant measurement standard instructions and broadcast signal materials should be clearly referred to, the procedure and broadcast content or test pattern should be distinctly defined, similar to the current Chinese standard.

Acknowledgements

The test could be carried out thanks to the participation of the test institutes and its experts, of Topten China and CLASP China:

CVC: Guangzhou Vkan Certification & Testing Institute, China National Center for Quality Supervision & Test of Electrical Appliances. Guangzhou, China: Chen Yongqiang and Judy Zhu. www.cvc.org.cn/

NIM: National Institute of Metrology. Beijing, China. Wu Tong and Shen Qingfei. http://en.nim.ac.cn/

VDE: Association for Electrical, Electronic and Information Technologies VDE. Offenbach, Germany. Gerhard Heine und Patrick Moebs. www.vde.com/en

Top10 China: Zheng Tan. www.top10.cn, and CLASP China: Li Jiayang. www.clasponline.org

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Smart Appliances: The Future of Appliance Energy Efficiency

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Abstract

Home appliances have made great strides over the last 20 years in improving machine efficiencies, but the traditional mindset of continually increasing machine efficiencies is leading to diminishing returns in terms of kilowatt-hour savings. However, there are yet untapped and plentiful efficiencies that can be achieved through an integration of smart appliances and the smart grid.

Smart appliances can provide energy savings which lead to consumers saving money, but there are challenges that need to be overcome. Home appliances, especially smart appliances, are a critical component to a modern electric grid in order to manage electrical energy more efficiently and effectively. In order to make the smart grid a reality, utilities and regulators must develop a new way of thinking and be willing to integrate innovative technologies such as smart appliances as part of the broader goal of increasing grid efficiency.

It is of utmost importance to recognize that smart appliances provide energy savings. By shifting residential load from peak times of day to when there is less demand for electricity, the entire power system is less costly and operates more efficiently. For example, in order to match supply and demand at all times, power system operators maintain spinning reserves that are invoked in the event of a contingency. These reserves are a necessary, but wasteful and expensive, component of the current electrical grid to maintain real time matching of supply and demand. Instead of generators supplying spinning reserves, electrical loads such as smart appliances can be used to instantaneously adjust demand to match supply – a new way of thinking, a lower cost option, and a more environmentally friendly path to the future.

Introduction

Home appliances have made great strides over the last 20 years in improving machine efficiencies. Clothes washers use 70 percent less energy and refrigerators use half the energy. Today's average refrigerator uses less energy than a 60 watt light bulb. Another 10 percent improvement in refrigerator machine efficiency would achieve less than a 6 watt savings in power, but envision a smart refrigerator that can shift 500 watts of defrost power or ice-making power to periods when electrical demand is low or renewable energy is plentiful. Instead of continuing down the path of ever increasing appliance efficiencies, it is required to change focus to new areas with greater potential. The traditional mindset of continually increasing machine efficiencies is leading to diminishing returns in terms of kilowatt-hours in savings, as opposed to the yet untapped and plentiful efficiencies that can be achieved through an integration of smart appliances and the smart grid.

Of utmost importance is recognition that smart appliances provide energy savings (both machine and grid system savings). By shifting residential load from peak times of day to when there is less demand for electricity, the entire system is less costly and works more efficiently because of less congestion in the transmission lines and distribution system. The regional generation mix of base-load, intermediate-load, and peak-load generation type certainly influences the use of demand response capability, but these inherent inefficiencies in the current system lead to the need for "spinning reserves," which can be idling power plants needed to protect the system reliability. These reserves are a necessary, but wasteful and expensive, component of the current electrical grid to maintain real time matching of supply and demand. It is such an important part of the electrical grid that spinning reserves have their own market and pricing structure.

Traditionally, the need to match supply and demand of electricity has always been met by adjusting supply (generation), i.e., invoking reserves that are set aside to compensate for any imbalance between supply and demand. But adjusting demand instead of supply can be instantaneous and clean. Electrical loads from smart appliances can be used to instantaneously adjust demand to match supply – a new way of thinking, a lower cost option, and a more environmentally friendly path to the future.

There are challenges that need to be overcome to make a smart grid a reality. For example, consumer use and acceptance of smart appliances is critical. For this to occur, the consumer must have complete control of his or her appliance. However, the appliance needs to adjust its operations automatically so that lifestyle and behavioral changes are minimized, and electricity must be priced dynamically throughout the day so that the consumer can save money on his or her electricity bill by allowing reminders and unobtrusive operational changes to be made automatically. The appliance should use a “set it and forget it” type of model for the smart grid capabilities so that consumers will not have to continually monitor price signals and monitor their behavior continuously.

Smart appliances provide a significant contribution to energy efficiency and the development of a smart grid, which will improve efficiencies, increase the use of renewable energy, reduce costs, and increase reliability. However, there need to be incentives to manufacturers to sell smart appliances to hasten the development of an effective smart grid. One of the incentives recently implemented by the US Environmental Protection Agency (EPA) is the integration of smart capabilities into ENERGY STAR specifications as mentioned in the White House Office of Science and Technology’s recent report titled “A Policy Framework for a 21st Century Grid: A Progress Report.” This report provides a national policy on modernization of the electric grid and states “a modernized electric system will also provide a foundation for innovative new products and services that can help families and businesses save money.”

According to the report, “In another effort to improve end-user energy experiences, EPA is exploring the potential benefits of strategically connecting ENERGY STAR product functionality to the smart grid. EPA and its ENERGY STAR partners are focusing initially on residential refrigerators and freezers, room air conditioners, climate controls, and pool pumps, which, if connected to the smart grid, could potentially communicate with other devices in a home and enable information-sharing between and access control from networked devices such as personal computers, televisions, and smart phones. In the future, such connectivity could enable preferential operation of electricity systems when costs are lower or when renewable sources of energy are more plentiful.”

Currently, the EPA has agreed to allow a 5% allowance for smart appliances on the energy levels in order to meet ENERGY STAR qualifications as an incentive to appliance manufacturers. EPA completed the Refrigerator/Freezer ENERGY STAR Specification on May 31, 2013, and proposed a similar allowance for clothes washers on June 5, 2013. EPA intends to also provide the same incentive for room air conditioners and other appliances to help jumpstart the smart grid.

The Problem: Electricity Use Is Increasing

The U.S. Energy Information Administration (EIA) projects that world net electricity generation will increase by 87 percent, from 18.8 trillion kilowatthours in 2007 to 25.0 trillion kilowatthours in 2020 and 35.2 trillion kilowatthours in 2035. And for world residential energy use the projection is an increase of 1.1 percent per year, from 50 quadrillion Btu in 2008 to 69 quadrillion Btu in 2035, or a 38 percent increase in electricity use by 2035.[i]

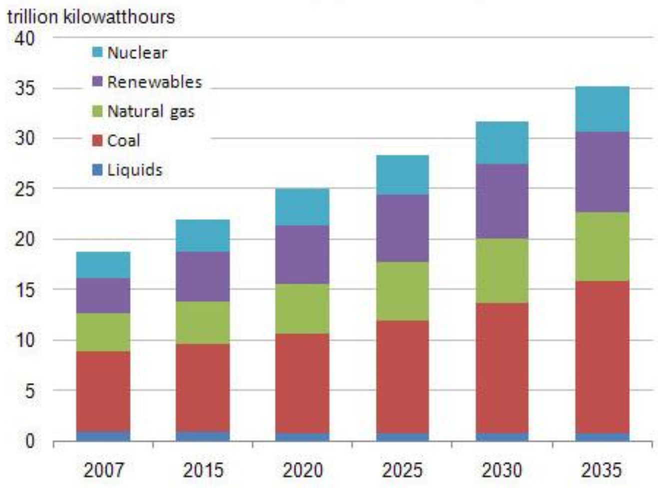

Figure 1: World Electricity by Fuel (Source: EIA 2010 International Outlook)

Peak demand increases may be even more pronounced. One industry forecast of peak demand, which extrapolates the North American Electric Reliability Corporation's 2005 Peak Demand and Energy Projection Bandwidths, predicts non-coincident peak demand that is 55 percent higher in 2030 than it was expected to be in 2008.[ii] Summer peak load was expected to increase 430 GW in 2030 from the existing 781 GW. This forecast does not include expected demand response programs, but does include modest forecasted efficiency savings. Peak demand is the most costly because 10 percent of the generation and 25 percent of the transmission infrastructure are needed to service only 400 hours per year (see Figure 2). However, the EIA 2010 Annual Energy Outlook projects that the U.S. electric power sector generating capacity will grow by only 8 percent from 2010 to 2030.

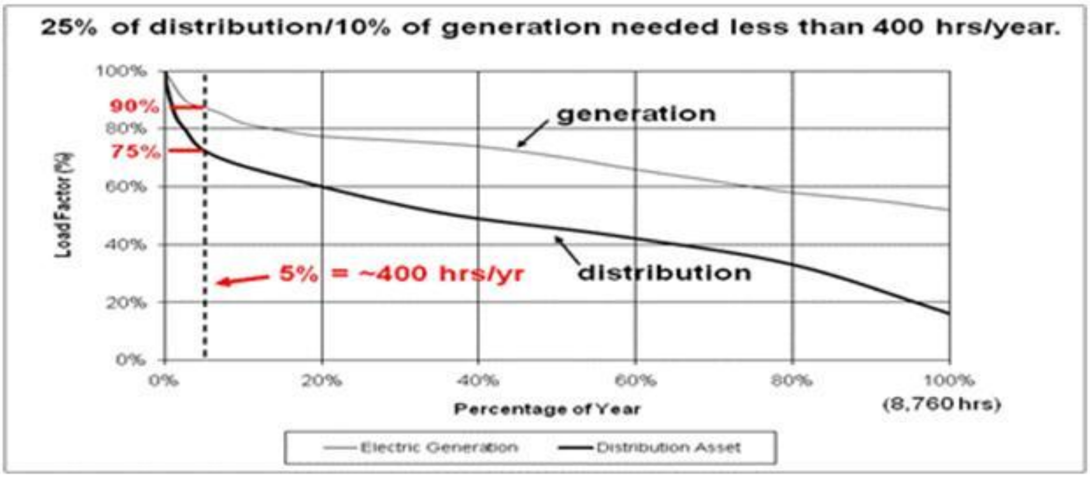

Figure 2: Distribution/Generation Needs (Source: Pacific Northwest National Laboratory)

The Smart Grid Is Critical in Addressing the Increase in Electricity Use

The smart grid is an important part of efforts to address projected increases in electricity use. The Electric Power Research Institute (EPRI) estimates that the implementation of smart grid technologies could reduce electricity use by more than four percent annually by 2030.[iii] And the residential sector is critically important to managing the electrical grid into the future. The residential sector represents 37 percent of electricity use in the U.S. and is the largest consuming sector of electricity (see Figure 3).

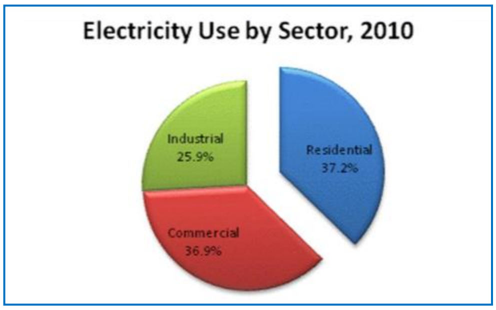

Figure 3 (Source: EIA Annual Energy Outlook)

Demand response, augmented by the smart grid and smart appliances, will result in some energy savings and reductions in costs. The North American Energy Standards Board (NAESB) has defined demand response as "changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentives designed to induce lower electricity use at times of potential peak load, high cost periods, or when systems' reliability is jeopardized."[iv] In other words, when an electric utility company or third party energy service provider encounters a problem, it can send a signal alerting the consumer of the complication so that the consumer can react by reducing load. Critical time reductions of energy use can be accomplished by either "shifting" usage to a non-critical time of the day or by "shedding" load to reduce peak power.

According to EPRI ". . . load reductions offered by demand response and load control programs facilitated by a Smart Grid can yield energy savings and reductions in carbon emissions."[v] And former U.S. Department of Energy Secretary Chu has recognized that "[s]mart grid technologies will give consumers choice and promote energy savings, increase energy efficiency, and foster the growth of renewable energy resources."[vi] Further evidence that reducing peak power is linked to saving energy is the EIA's 2008 Electric Power Annual Report at Table 9.2 in which utilities reported for every 1kW of peak load reduction there is a corresponding 139 kWh of energy saved.

Reducing peak load provides several other benefits:

- reduces transmission congestion
- minimizes operation of peaking plants
- defers the need for new generation

According to a report released by U.S. Vice President Biden on August 24, 2010:

> *Smart Grid technology, combined with supportive policy, allows for smarter use of energy, largely by increasing the transparency, measurement, and control of energy used by the players who supply, transmit, distribute, and demand it. Through automated sensors and controls as well as dynamic pricing, this intelligent infrastructure will make the electric system more reliable, empower consumers and utilities to use energy more wisely, help manage peak demand, enable larger scale use of renewable energy and electric vehicles, and reduce U.S. dependence on oil.*[vii]

Reportedly in Europe, the smart grid could save €52 billion.[viii] The sizeable savings would arise from reducing losses in the electricity distribution network through automation and encouraging consumers to cut energy consumption with smart meters that provide more accurate and timely information, according to experts from the Smart Energy Demand Coalition in Brussels.

Smart Appliances Used as Spinning Reserves

To balance supply and demand continuously despite sudden, unexpected failures of generators and/or transmission lines, utilities typically maintain contingency reserves to compensate for such failures. Contingency reserves include 10-minute spinning reserves, 10-minute non-synchronized reserves, and 30-minute operating reserves. The 10-minute spinning reserves are typically provided by base-load generators operating below their rated capacity and then ramping them up when called upon. Despite their importance to power system operation, the larger the spinning reserve requirement, the greater the emissions and capital costs for limited operation. This is a wasteful, but necessary, part of the current U.S. electrical grid.

Reserves are a significant cost to the system which is passed down to the consumer. Figure 4 shows the reserve margins around the U.S.[ix] Regional rules differ but typically, sufficient reserves in the form of capacity must be set aside to be invoked in the event of the largest credible contingency, which could be the loss of a generator or a transmission line. Such reserves are referred to as contingency reserves. Typically, half of the contingency reserves have to be spinning, i.e., available in 10 minutes. As an example, in the Electric Reliability Council of Texas (ERCOT), which operates the electric grid and manages the deregulated market for 85 percent of the state's load, typically has to maintain 2,500 MW of spinning reserves in case both nuclear generators go down. This represents 5-7 percent of the total load in the area.

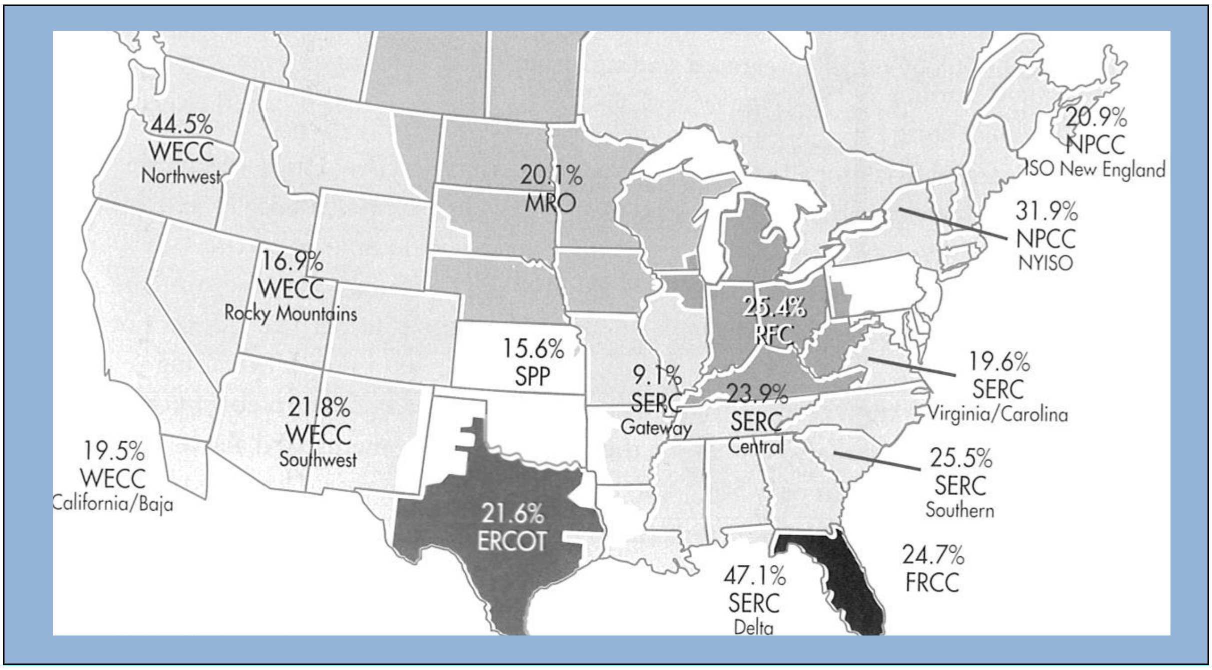

Figure 4: Summer 2009 Reserve Margins By Region (Source: NERC 2009 Summer Assessment)

Fortunately, there is another way -- a cheaper, cleaner, more efficient way -- of handling spinning reserve requirements. It can come from load (demand) instead of generation (supply). If it comes from load it is "green" because it avoids additional generation and unused "idling" generation. In recent years, there has been considerable interest in exploiting the enormous potential of demand response towards providing spinning reserves.[x] This is over and beyond peak-load reduction. Residential loads capable of interacting with the grid (smart appliances) such as refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers are particularly suited as sources of 10-minute spinning reserves because the operation of such loads can be interrupted for short periods without causing any diminution of the quality of service for consumers. Furthermore, end-uses can often be curtailed almost instantaneously as opposed to generators that must ramp up and down subject to operating constraints in order to avoid equipment damage. Finally, given the potentially large number of responsive end-use loads, their aggregate response could be extremely reliable when called upon to provide alternative to traditional spinning reserves. Thus, residential loads could obviate the need for maintaining some fossil-fuel based generation for providing spinning reserves thereby reducing operating costs and also lowering emissions.

Consumers will save money when smart appliances are used for spinning reserves. One recent study sponsored by PJM[xi] and the Mid-Atlantic Distributed Resources Initiative estimates that a three percent load reduction during peak could reduce electricity prices by up to 12 percent. This price reduction corresponds to approximately $330 million in savings per year, of which $20 million is estimated to be saved by the demand-reducing customers. Two to three times that amount would be saved by other customers in the Mid-Atlantic States due to lower market prices, and $8-12 million would be saved by customers outside the region.

Benefits of Smart Appliances

The Pacific Northwest National Laboratory (PNNL), which is a U.S. Department of Energy (DOE) laboratory, undertook an in-depth analysis to evaluate the precise benefits of smart appliances (refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers) towards providing both peak-load reduction and spinning reserves through demand response.[xii] In this report, PNNL presents the results of a cost/benefit study of residential smart appliances from a utility/grid perspective. This study was prepared as an independent technical analysis of a joint stakeholder[xiii] petition to the ENERGY STAR program within the Environmental Protection Agency (EPA) and DOE. The goal of the petition is, in part, to provide appliance manufacturers incentives to hasten the production of smart appliances and jump start the development of the smart grid. The underlying hypothesis is that smart appliances can play a critical role in addressing some of the societal challenges, such as anthropogenic global warming, associated with increased electricity demand, and facilitate increased penetration of renewable sources of power.

<u>The PNNL analysis found that the benefits derived from a smart appliance are more than equivalent to a corresponding five percent change in operational machine efficiencies</u>. It is expected that given sufficient incentives, value propositions, and suitable automation capabilities built into smart appliances, residential consumers will adopt these smart appliances and more effectively manage their home electricity consumption.

The analytical model used in the cost/benefit analysis consists of a set of user-definable assumptions such as the definition of “on-peak” (hours of day, days of week, months of year), the expected percentage of normal consumer electricity consumption (also referred to as appliance loads) that can be shifted from peak hours to off-peak hours, the average power rating of each appliance, etc. Based on these assumptions, the wholesale grid operating-cost savings, or “benefits,” that would be realized if the “smart” capabilities of appliances were invoked was estimated. The benefits considered were peak-load shifting for some percentage of appliance loads and ancillary services provided by responsive appliance loads. Specifically, responsive or dispatchable smart appliance loads that meet power system needs for spinning reserves that would otherwise have to be provided by generators were considered in this study. The rationale for this is that appliance loads can be curtailed for about ten minutes or less in response to a grid contingency without any reduction in the quality of service to the consumer.

A summary of the results is provided in Table 1 and Table 2. It shows that in virtually all the markets, in either optimistic or pessimistic assumption scenarios, the benefit-to-cost ratio for the addition of smart grid capabilities in appliances exceeds a corresponding change of 5 percent in traditional machine efficiencies, and in some cases by more than tenfold.

Table 1: Benefit-to-Cost Ratios of Smart Appliances Based on “Optimistic” Assumptions

	DW	CW	RAC	Freezer	Refrigerator	Dryer
PJM 2006	528%	563%	733%	539%	536%	680%
ERCOT 2008	817%	871%	1060%	881%	877%	1054%
NYISO 2008	367%	403%	585%	357%	355%	462%
NYISO 2006	353%	389%	712%	346%	344%	442%
CAISO 2008	319%	356%	554%	313%	312%	396%

Table 2: Benefit-to-Cost Ratios of Smart Appliances Based on “Pessimistic” Assumptions

	DW	CW	RAC	Freezer	Refrigerator	Dryer
PJM 2006	136%	134%	131%	150%	150%	207%
ERCOT 2008	203%	200%	295%	230%	228%	337%
NYISO 2008	107%	106%	139%	112%	111%	147%
NYISO 2006	112%	112%	160%	119%	118%	160%
CAISO 2008	99%	100%	135%	102%	101%	134%

Another important finding of the PNNL study is that the benefits are spread across peak-load shifting, spinning reserve, and feedback effect. Tables 3 through 8 show this spread for the optimistic scenario.

Table 3: Percentage of Total Smart Refrigerator Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	8%	70%	22%
ERCOT 2008	9%	78%	14%
NYISO 2008	11%	56%	34%
NYISO 2006	11%	54%	35%
CAISO 2008	12%	49%	39%

Table 4: Percentage of Total Smart Freezer Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	8%	70%	22%
ERCOT 2008	9%	77%	14%
NYISO 2008	11%	55%	34%
NYISO 2006	12%	53%	35%
CAISO 2008	13%	49%	38%

Table 5: Percentage of Total Smart Room Air Conditioner Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	63%	20%	16%
ERCOT 2008	41%	48%	11%
NYISO 2008	55%	25%	21%
NYISO 2006	65%	18%	17%
CAISO 2008	63%	15%	22%

Table 6: Percentage of Total Smart Clothes Washer Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	31%	47%	21%
ERCOT 2008	37%	49%	14%
NYISO 2008	40%	30%	30%
NYISO 2006	42%	27%	31%
CAISO 2008	46%	20%	34%

Table 7: Percentage of Total Smart Clothes Dryer Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	28%	55%	18%
ERCOT 2008	33%	56%	11%
NYISO 2008	37%	37%	26%
NYISO 2006	40%	33%	27%
CAISO 2008	44%	25%	30%

Table 8: Percentage of Total Smart Dishwasher Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect

Market and Year	Peak-Load Shifting	Spinning Resreves	Feedback Effect
PJM 2006	26%	52%	23%
ERCOT 2008	31%	54%	15%
NYISO 2008	33%	34%	33%
NYISO 2006	35%	31%	34%
CAISO 2008	39%	23%	38%

Demand Response vs. Energy Efficiency

Increasing machine energy efficiency is not the only way to drive energy savings. Demand response can also yield some energy savings. For example, cycling the dryer heating coil off while continuing to spin clothes allows use of the residual heat in the dryer, reducing heater-on time when the heater coil is restarted and yielding less total cycle energy use, but this also increases cycle time, which consumers are not enthusiastic about doing all the time. The residential consumer and smart appliances are important to the success of demand response. Since late 2007 and after passage of a U.S. energy law in 2007, for example, efficiency savings were estimated by the Electric Power Research Institute (EPRI), including savings from refrigerators, dryers, room air conditioners, clothes washers, and dishwashers. EPRI found that the savings from these appliances were a small percentage of maximum achievable potential in 2030 in relation to other residential, commercial, and industrial uses.[xiv] As appliance efficiency continues to increase, remaining opportunities for appliance efficiency savings will decline. Further information from the EPRI study is shown in Figure 5, which depicts that the maximum potential for efficiency savings in home appliances (highlighted in chart) is quite low compared with other products. In addition, in a Whitepaper released this month (May 2011) by the Institute for Electric Efficiency found that “For utility programs, changes in efficient standards and building codes may make it increasingly challenging to achieve energy savings through traditional energy efficiency programs, particularly those that target individual appliances and equipment.”[xv]

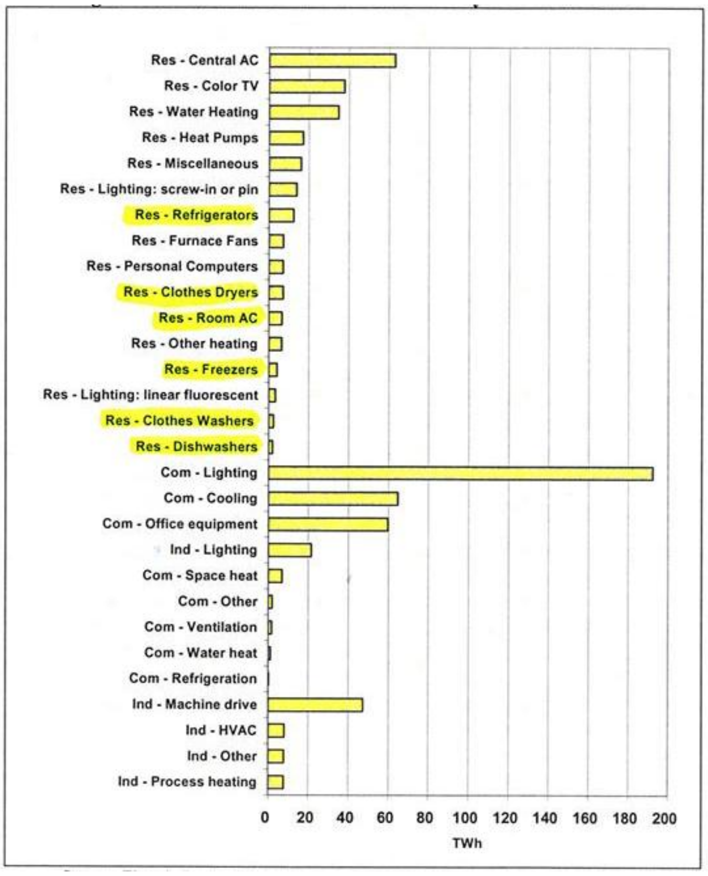

Figure 5: Maximum Achievable Potential by End Use in 2030
(Source: Electric Power Research Institute)

According to the EPRI assessment of achievable potential for energy efficiency and demand response in the U.S., demand response combined with increases in energy efficiency can offset 40 percent (173 GW) of the growth in summer peak demand by 2030 (see Figure 6).[xvi]

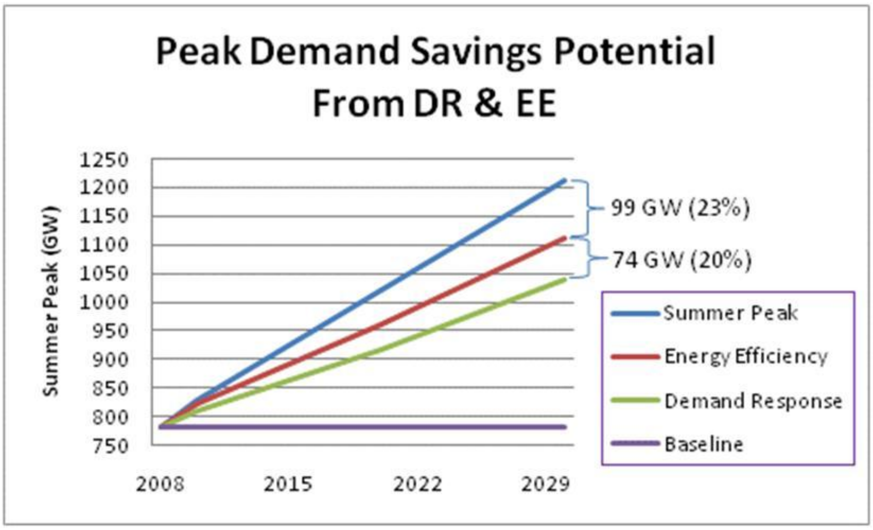

Figure 6: (Source: Rohmund, Ingrid, et. al, Assessment of Achievable Potential for Energy Efficiency and Demand Response in the US (2010-2030).)

Significantly, residential customers offer as much demand response potential as small, medium, and large businesses combined (see Figure 7).

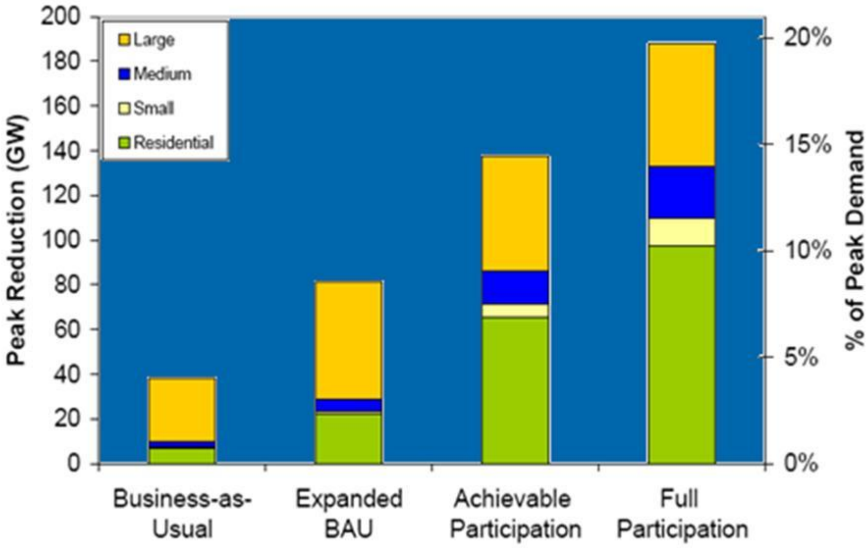

Figure 7: (Source: Federal Energy Regulatory Commission)

According to FERC, ". . . it is the residential class that represents most [sic] untapped potential for demand response. . . While residential customers provide only roughly 17 percent of today's demand response potential, in the AP [Achievable Participation] scenario they provide over 45 percent of the potential impacts."[xvii] The FERC National Assessment of Demand Response, June 2009, found that "pricing w/tech" (including smart appliances) offers more than half of the potential for peak demand reduction (see Figure 8). Furthermore, as the PNNL study indicates, further gains are possible through the utilization of smart appliances for providing spinning reserves.

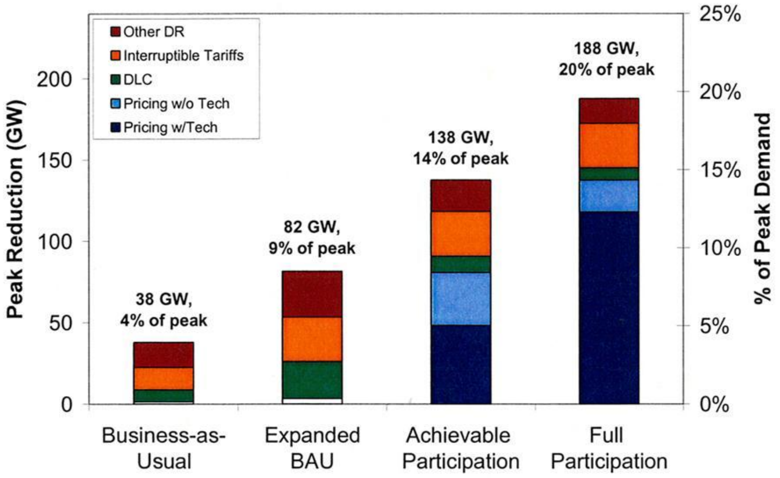

Figure 8: (Source: FERC National Assessment of Demand Response, June 2009)

Demand Reduction Yields Further Capacity Savings

Reducing demand also yields capacity savings. Reducing demand may have a 24 percent higher impact at the generating facility, which equates to even more capacity savings (see Figure 9).

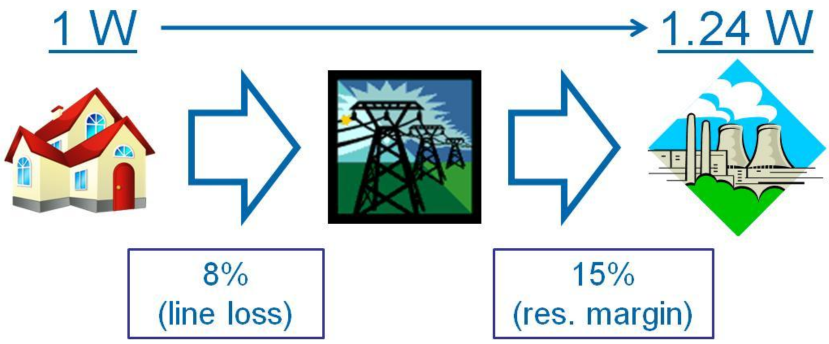

Figure 9: (Source: The Brattle Group, Power of 5%)

Transmission losses account for approximately two to four percent of the total electricity generated in the United States.[xviii] While the percentages may appear relatively low, the total amount of energy involved is considerable. The percentages equate to about 83 million MWh to 166 million MWh lost each year based on a total U.S. annual generation of 4,157 million MWh.[xix]

Increased Use of Renewable Energy

The benefit of the smart grid goes beyond energy savings. Due to environmental concerns, there has been increasing interest in recent years towards incorporating large amounts of renewable sources of energy such as solar and wind, and diminish the reliance on fossil-fuels to create a more diversified energy supply portfolio. For example, DOE has initiated a collaborative effort to explore the possibility of wind power supplying 20 percent of U.S. electricity needs by the year 2030.[xx] One of the key challenges involved with solar and wind as sources of energy is that they are intermittent and cannot be relied upon with certainty. Solar energy output can drop very quickly with passing clouds, while wind energy output changes very frequently, almost every hour. As a result, in order to balance supply and demand, a key objective of power system operation alluded to above is that energy reserves are required to be maintained based on conventional generation sources like natural gas. But doing so works against the very purpose of incorporating solar and wind energy, namely, decreasing reliance on fossil fuels. Fortunately, demand response through smart appliances can be invoked to curtail and/or defer demand for power during periods when solar and wind energy are in short supply, and to shift the demand to when there is an abundance, enabling greater utilization of renewable energy.

Thus, smart appliances and smart grid can play an important role in facilitating greater utilization of intermittently available renewable resources such as solar and wind, from which will accrue reductions in CO_2 emissions.[xxi] The intermittent nature of the renewables is a critical impediment to their greater impact. By developing a truly smart grid that can shift demand to when supply is available, this impediment gets reduced significantly. A dynamic response system like that envisioned for residential usage of smart appliances will enable renewable energy to become a more significant part of the total energy picture.

Smart Appliances Will Also Help Reduce Carbon Emissions

PNNL published a study that estimates the role of smart grid towards reducing carbon emissions.[xxii] In particular, the study evaluated the carbon reductions through nine smart grid mechanisms. PNNL found that carbon emissions can be reduced directly through smart grid applications, and indirectly by investing the operational savings resulting from smart grid into renewable sources of power generation and efficiency programs. The table below (see Figure 10) summarizes the study's findings including the key conclusion: smart grid may facilitate a 12 percent direct carbon reduction, and a 6 percent indirect reduction.

Mechanism	Electric Sector Energy CO_2 Reductions	
	Direct	Indirect
Conservation Effect of Consumer Information and Feedback Systems	3%	-
Joint Marketing of Efficiency and Demand Response Programs	-	0%
Diagnostics in Residential and Small/Medium Commercial Buildings	3%	-
Measurement and Verification for Efficiency Programs	1%	0.5%
Shifting Load to More Efficient Generation	< 0.1%	-
Support Additional Electric Vehicles (EVs) / Plug-In Hybrid Electric Vehicles (PHEVs)	3%	-
Conservation Voltage Reduction and Advanced Voltage Control	2%	-
Support Penetration of Solar Generation (RPS > 25%)	(1)	(2)
Support Penetration of Wind Generation (25% RPS)	< 0.1%	5%
Total, Share of U.S. Electric Sector Energy and CO_2 Emissions	12%	6%

Figure 10: Nine Smart Grid Based Carbon Reducing Mechanisms (Source: PNNL, The Smart Grid: An Estimation of the Energy and CO2 Benefits)

The PNNL study does not explicitly identify the role of smart appliances in carbon reductions, but smart appliances could play a role in several of the carbon reducing mechanisms in the above table.

Smart Appliances Will Help Consumers Save Money

Smart appliances will also benefit the consumer. The development of smart grid tools for consumers will enable both utilities and consumers to use electricity more efficiently, thereby reducing their costs.[xxiii] For example, dynamic pricing of electricity creates the conditions that encourage consumers to change their or the appliances' behavior by using appliances when the rates are lower, which if properly developed to minimize the need for behavioral changes by the consumer, will save consumers money on their total electricity bill. According to FERC's Assessment of Demand Response and Advanced Metering Report, there were an estimated 7.95 million installed advanced meters nationwide in 2009. These smart meters are already helping to reduce energy costs for families and businesses.[xxiv] As stated above, EPRI estimates that the implementation of smart grid technologies could reduce electricity use by more than four percent annually by 2030, which would mean an electric bill savings of $20.4 billion for consumers and businesses around the country <u>each year</u>.[xxv]

Conclusion

We must be mindful of the current problems associated with an antiquated U.S. electrical Grid that is based on 100 year old technology in some parts. Electricity is being used in the home to power many other hi-tech products. Today, low frequency of blackouts is due to several reasons, such as spinning reserves and the improved technologies of the grid's control center operations. Nevertheless, the dichotomy of 21st Century products, such as computers and iPhone, being powered by some technologies developed during the "horse and buggy" era highlights the need to modernize our electrical grid.

As this paper outlines, electricity use is increasing and peak power capacity, which is the most expensive part of the system, is increasing more quickly. It is time to trim some of the waste in the current system by developing an effective smart grid by integrating innovative technologies and services. Products such as smart appliances should be incentivized by governments to provide a national framework and platform such as through ENERGY STAR.

Such a national program will allow manufacturers to deploy smart appliances in the home while still allowing homeowners to maintain control of their appliances with the highest level of convenience.

Home appliance manufacturers are enthusiastic about the contribution their products can make to jump starting the development of the smart grid. But appliance manufacturers cannot do this alone. No one can. In the manufacturing engineering world, there is a saying that there is a time to stop designing and start manufacturing. We are pleased with the huge progress that has been made just in the last year with the acknowledgement of smart appliances in the ENERGY STAR program Now it is time to provide incentives in the EU and other areas of the world to make the smart grid a reality.

Endnotes

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[i] U.S. Energy Information Administration, "2010 International Outlook," available at www.eia.doe.gov/oiaf/ieo/index.htmlk.

[ii] Ingrid Rohmund and Greg Wikler (Global Energy Partners, LLC), Ahmad Faruqui (The Brattle Group), Omar Siddiqui (Electric Power Research Institute) and Rick Tempchin (Edison Electric Institute), *Assessment of Achievable Potential for Energy Efficiency and Demand Response in the U.S. (2010 – 2030)*, Paper prepared for 2008 ACEEE Summer Study on Energy Efficiency in Buildings, p. 5-264.

[iii] Press Release, U.S. Department of Energy, "Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide (August 31, 2010)," ***available at*** www.energy.gov/news/9433.htm.

[iv] Recommendation to NAESB Executive Committee (July 29, 2009), "Measurement & Verification for Demand Response Programs."

[v] Electric Power Research Institute, "The Green Grid," June 2008

[vi] Press Release, U.S. Department of Energy, "Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide" (August 31, 2010), ***available at*** www.energy.gov/news/9433.htm.

[vii] Executive Office of the President of the United States and Vice President of the United States, "The Recovery Act: Transforming The American Economy Through Innovation," at 37 (August 2010), available at www.whitehouse.gov/sites/default/files/uploads/Recovery_Act_Innovation.pdf (emphasis added).

[viii] Available at http://www.euractiv.com/en/energy-efficiency/smart-grids-could-save-europe-52bn-news-499738, November 2010

[ix] Reserve margins are the extra supply that is available. It is calculated as the total supply capacity minus the peak demand, divided by the peak demand.

[x] B. J. Kirby, Oak Ridge National Laboratory, "Spinning Reserve From Responsive Load" (March 2003), available at certs.lbl.gov/pdf/spinning-reserves.pdf

[xi] Quantifying Demand Response Benefits In PJM: http://pjm.com/documents/media/reports/brattle-report-quantifying-demand-response-benefits-pjm.ashx

[xii] Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves

[xiii] Stakeholders include Association of Home Appliance Manufacturers, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Consumer Federation of America, and others.

[xiv] Rohmund, Ingrid, et. al. (Global Energy Partners, Brattle Group, EPRI, EEI), "Assessment of Achievable Potential for Energy Efficiency and Demand Response in the US" (2010-2030).

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[xxiv] Press Release, U.S. Department of Energy, "Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide" (August 31, 2010), ***available at*** www.energy.gov/news/9433.htm.

[xxv] *Ibid.*

Improving Energy Efficiency with Smart Home Appliance Monitoring

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Abstract

Current smart home systems are often expensive, with a focus on luxury and comfort, rather than energy efficiency. Smart meter technology is slowly rolling out in the UK through trials (with every home to be fitted with one by 2020), bringing the potential for automated load management in the future. There is a clear demand for home energy management today, and with more and more people and devices connected via the Internet ("The Internet of Things"), there is an opportunity to meet this demand by integrating data analytic tools with current smart home technology.

This paper presents an in-depth survey of smart home technology kits, yielding our proposed energy monitoring, communication and visualisation platform that overcomes limitations of existing smart home kit, as well as some initial results of the analytics to help homeowners reduce energy by analysing smart home data for energy consumption patterns and understanding how electrical appliances are used. Additionally, we show how we can predict and potentially improve energy efficiency by correlating alternative sensor data with energy data to building mathematical models of appliance energy consumption as a function of a range of measurands. An energy smart kettle example is given in this paper whereby energy consumption is modeled, derived from measurements of temperature, power and the amount of water used. These will help develop tools for improving energy efficiency in everyday activities by analysing the collected data from appliances and sensors, providing feedback as to aspects of energy usage and advising of more efficient ways of operation or retrofit upgrades.

1.0 Introduction

As the UK prepares for the roll-out of smart meters, electricity use is in fact on the increase, with households containing more electrical appliances than ever before. A recent report commissioned by the Energy Saving Trust [1] indicates that a household contains on average 40 electrical appliances or devices and that 16% of energy use is from devices on standby, showing the need for better consumer advice to manage appliance use efficiently.

There is a trend in home energy management systems (HEMS) to investigate the impact of smart home technology on reducing energy consumption using decision support tools[2]. Decision support tools form a key component of HEMS to advise on better appliance management and building envelope retrofit solutions based on user behaviour and engagement with smart home technology. In order to start this process, we have developed an energy monitoring platform to be deployed into a number of households to collect data on how and when appliances are in use in these homes, and how households react to visual energy consumption feedback, by taking advantage of the monitoring and display facilities available in modern smart home systems and related devices.

This paper presents an in-depth survey of smart home technology and monitoring techniques, our proposed energy monitoring and visualisation platform that overcomes some of the latter's limitations and exploits their advantages, and an example of the initial analytical work carried out using the data gathered from our platform that senses and communicates not only energy readings but other measurands such as temperature.

In this paper we first survey smart home technology and energy monitoring techniques, then describe how we perform energy monitoring using aggregate and individual energy sensors or monitors, and finally give an example of appliance modeling, by analysing the energy consumption of a conventional kettle, to determine how it performs, and the energy that can be saved through understanding its use. This analysis has provided a methodology for appliance performance prediction by modeling certain characteristics and behaviour.

2.0 Smart Home concept

Smart home technology has existed in some form since the 1970s, with the introduction of the X10 protocol, a primitive, yet innovative for the time, signaling technology which operated over the household's existing electrical wiring. Originally developed in Scotland, one of the key features of the X10 concept was the ability to turn appliances on and off using remote control over the electrical mains network. Later elements of automation were added with sensors aiding control to switch devices or lights on or off based on occupancy, temperature or luminance levels. The focus was on luxury, security, comfort and convenience, rather than energy saving.

The mid 80s saw the introduction of the X10 HomeMinder system, one of the first smart home automation systems, allowing control of lights, appliances, heating and cooling, all operated from a simple user interface on a television set.

2.1 Communication Protocols

The evolution of smart home systems has coincided with the rapid development of computers, mobile devices, wireless technology and building automation technology found in large buildings. Presently, the smart home market is fragmented with several competing communication protocols such as KNX, LonWorks, Zigbee and Z-Wave, all operating over various communication channels, for wired and wireless transmission. These protocols have varying degrees of application across different types of buildings. For instance KNX can be scaled to very large buildings such as Airports, but can also be used to create smart homes, albeit at significant cost. While LonWorks and KNX cater for the high-end market, protocols such as Z-Wave and 433MHz based systems such as HomeEasy and LightwaveRF provide affordable solutions. Simpler protocols only support unidirectional control (e.g., 433MHz), though most offer full bi-directional communication, which permits querying of state (whether a device has been manually operated on or off). Interoperability between protocols is also an issue, as they all operate over different radio frequencies, and have incompatible signaling methods. Bridging by using middleware frameworks (e.g., Hydra, Niagara) and IP (Internet Protocol) is possible, and some more recent solutions include multiple interface integration. The prevalence of IP and gradual deployment of next generation IPv6 is also stimulating development of new hybrid protocols such as Zigbee IP, which combines the benefits of IPv6 with the characteristics of Zigbee wireless mesh networking. Table 1 outlines some of the most popular protocols for smart home and building automation, contrasting the advantages and disadvantages of each.

Protocol	Communication	Advantages	Disadvantages
KNX	Cabling, Power line, Wireless (868MHz)	Solutions fit for all kinds of building (from small houses - airports)	Expensive, complex software tools to configure
LONWORKS	Cabling, Power line, Wireless (900MHz/2.4GHz)	Good manufacturer support for large building automation	Need to pay a fee per node to include devices in network
ENOCEAN	Wireless (315/868MHz)	Battery-less energy harvesting	Expensive, limited control options
ZWAVE	Wireless (868/915MHz)	Wide range of devices from different manufacturers	Supports only 232 nodes
ZIGBEE	Wireless (868/915MHz/2.4 Ghz)	Can support up to 65,000 nodes in a network	2.4 Ghz based devices have short range
X10	Power line / Wireless	Very low cost	Old technology, can be unreliable
INSTEON	Power line / Wireless (902-924MHz)	Backwards compatible with X10	Few products on the market
HOMEEASY/ LIGHTWAVE RF	Wireless (433MHz)	Cheap, and quick operation	Not a wireless mesh network; nodes cannot be queried for state

Table 1: Smart Home and Building Automation Protocols

Smart Homes provide rich features across several areas. Each area will be briefly discussed.

2.2 Comfort & Convenience

Smart Home technology is often perceived as an enabler of improved comfort and convenience by giving the ability to interact with the living environment. This interaction is made possible by integrating communication modules into actuators such as light switches and thermostatic radiator valves, which then further introduce remote operation or conditional automation. The communication modules operate using the protocols outlined in Table 1, and when combined with Internet connectivity, allow remote setting and control of lighting, heating or even door locks. For example, one can activate heating remotely using a smartphone before arriving home, or open an entrance door from a remote location to allow someone to enter a house. Automation is made possible by programming scenes, which, in the context of smart home technology, are a set of operations which are performed once a condition is met either by triggering a sensor or when a certain time is reached. For example, scenes can be created to group sets of lights and attribute various levels of lighting for different mood settings (e.g., Romantic, Dinner Party, etc). Similarly, scenes can be set for heating where groups of thermostats can be scheduled to operate at various set points throughout the day. A smarter approach would be to anticipate heating demand from smart home rule learning, and turn on the heating to reach a desired setpoint for occupant arrival [3].

2.3 Security & Safety

Sensors and actuators in a smart home can be used for multiple functions. In the context of security and comfort, a motion sensor now has a dual role; 1) to detect occupancy and turn devices on or off accordingly, and 2) to detect intruders during unoccupied hours. Similarly, light switches can be programmed to turn on during an evacuation procedure, and door locks set to automatically open during events such as a fire. The safety aspect is further enhanced with other sensors normally used for control, now being used to sense odd behaviour which may indicate a life threatening accident has occurred (e.g., significantly raised temperatures during a fire).

2.4 Energy

Recently, smart home technology has been perceived as a solution to reduce energy consumption in the home. By integrating energy monitoring sensors, scenes can be programmed to detect and react to peak consumption events and switch off devices if overall consumption reaches a certain limit. This form of local energy management provides a platform for smarter demand side management (DSM) using Smart Meter technology to connect the local home area network of smart home devices to the wider Smart Grid. Di Giorgio and Pimpinella [4] identify three reference scenarios for automated DSM. The first, based on the scene described previously, looks at managing the energy load through user specified automation, by managing devices and the times they are on. The second scenario describes dynamic Time of Use (ToU) tariffs based on changing energy price profiles. In this case, the bidirectional communication advantages brought by smart meters enable demand response, making ToU an attractive proposition to lower energy costs. The communication between the connected smart home and utility (via the smart meter) can also provide direct load control whilst also determining the best time to turn on a highly energy consumptive device. The third scenario is an extension of ToU, where consumers sign up to limit their energy consumption during an agreed period. If properly incentivised for consumers, the smart meter can provide greater energy savings.

3.0 Energy Monitoring

In this section we will discuss some of the methods used for energy monitoring of appliances. This is necessary to understand appliance use and identify potential energy savings. For instance, an appliance may start to consume more energy due to faulty usage, wear and tear or simply beyond what a consumer expects.

In order to give feedback and advice about energy use, we need to record the consumption of individual appliances directly or indirectly. Furthermore, we need adequate sampling rates to capture events for high consuming appliances, which are on momentarily, such as the microwave or kettle. There is a trade-off to be made between very high sampling rates (over a Hz) and cheap, off-the-shelf monitoring kit that samples at medium to low sampling rates (less than or equal to a Hz).

The simplest monitoring method is to deploy individual appliance monitors, and measure each appliance at the plug point. However, with an average number of 40 appliances in the home, this simply becomes impractical. From a technical standpoint, the collection of data will be impacted, due to limitations in the number of devices communicating their readings by personal area wireless communication, which is the method often used by these types of monitors to transmit data. Even with a more suitable communications medium (e.g., powerline), the installation of individual appliance monitors may be cumbersome, as some plug points may be inaccessible, or appliances may share a multi-gang extension. Furthermore, the cost becomes high, requiring one monitor per appliance.

The seminal paper by Hart [5] first describes non-intrusive techniques for appliance load monitoring to address these issues by using a single point energy disaggregation.

3.1 Non intrusive appliance load monitoring (NALM)

NALM is a technique used to separate the measured load into separate components from a single sensor. Disaggregation is possible, by identifying unique signatures that an appliance may produce from an aggregate load. Hart [5] provided an early foundation in the 1980s, but since then many enhanced solutions appeared.

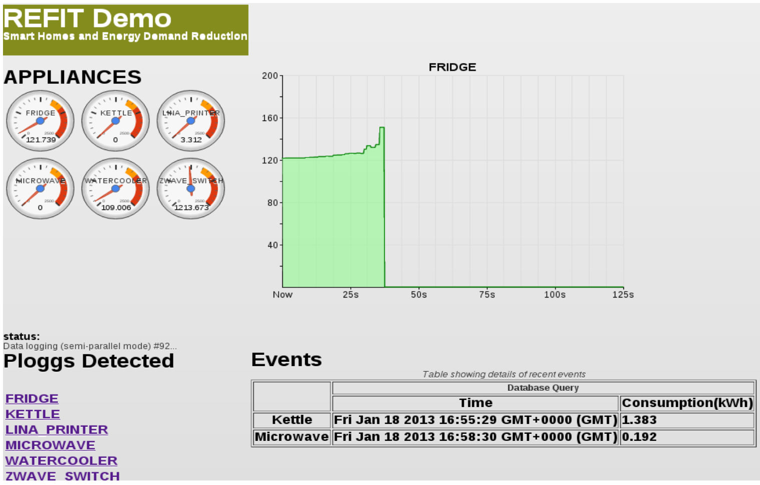
Disaggregation requires a well populated database of previously learned or recorded unique appliance signatures. There is a growing list of publicly available NALM datasets which can be used to apply disaggregation algorithms to databases with known appliances. Those of particular interest contain high frequency sampling current and voltage data, providing a richer dataset, and therefore more detailed characteristics can be extracted. Examples of these include the Reference Energy Disaggregation Dataset (REDD) [6] and Building-Level fUlly-labeled dataset for Electricity Disaggregation (BLUED) [7]. It was noted that even though the BLUED set sampled as high as

12kHz, all of the data beyond 300 Hz was redundant, due to low fidelity current sensors. The REDD set may also be subject to similar problems, due to the use of the same current transformers. High frequency sampling equipment is expensive, and not currently something an average household would typically invest in; thus, the authors are building their appliance database at the modest frequency of 1Hz or less. Furthermore, even though much research has scaled up to higher frequency sampling, there is very little effect on improving accuracy of detection. This could be due to low fidelity of sensors and limitations in communications. Recent advances in the area include the application of Artificial Neural Networks as a NALM disaggregation method [8], Fast Fourier Transform to perform disaggregation based on frequency components [9], and sensing EMI signatures over a powerline interface [10].

3.2 Real-time monitoring, communication and visualisation platform

For high consuming appliances and for experimental purposes, it is sometimes effective to monitor energy usage at the plug point. The Plogg energy monitor is one of the most comprehensive individual appliance monitors, giving voltage and current measurements transmitted via Bluetooth (IEEE 802.15.1) or Zigbee (IEEE 802.15.4), while also calculating effective and reactive power, consumed and generated. Ploggs also have logging capabilities, though limited to 20 hours of collection in one minute resolution. Omitting some values can extend the logging to 35 hours, but even then, it is not a suitable method of data retrieval over long periods of time. Adjustments can be made to log only during an event, which can prolong the retrieval period, but this feature is not appropriate for the aggregate sensor, which will be continually recording events such as vampire loads of appliances in standby, which would impact the disaggregation algorithms. Furthermore, the one minute sampling limitation makes it inadequate for attempting NALM to identify some common appliances (e.g., 30 second microwave events).

We have assembled an energy monitoring platform by accessing the Plogg network using Zigbee USB sticks, and performing Plogg management by serial port scripting under the Linux operating system. The plogglinux[1] script was modified to collect and write directly to an SQL database every second, which gives the ability for fast database querying actions, such as operations for pattern matching. SQL database queries can be used to determine when appliances were on, for how long, how much they consumed, and the associated cost during that period. This information is displayed on a web interface (Fig. 1), which also shows a list of Ploggs detected and dynamically draws real-time consumption gauges based on Google Chart. A selectable graph using the RGraph Javascript framework for dynamic graph creation shows the real-time consumption against time and plots effective power values over 125 sec. A Linux cron job scheduler calls a perl script every minute to check the presence of Ploggs, through a database query, to dynamically refresh the interface.



	Database Query	
	Time	Consumption(kWh)
Kettle	Fri Jan 18 2013 16:55:29 GMT+0000 (GMT)	1.383
Microwave	Fri Jan 18 2013 16:58:30 GMT+0000 (GMT)	0.192

Figure 1: Our monitoring interface that is updated in real time showing appliance monitors that are being detected, their energy readings and key events.

Other appliance monitors have been considered, such as the Current Cost range, which measures and transmits power values using a custom 433 MHz based protocol (C2) every 6 seconds. However,

[1] http://code.google.com/p/plogglinux/

as the Current Cost monitors only measure current, they can only provide effective power measurement, and without voltage sensing, cannot monitor reactive power, phase or frequency, which are variables that aid disaggregation. Other advantages the Ploggs bring include the ability to name them, simplifying querying operation and user interface management. Some other notable appliance monitors which only measure effective power, include the PlugWise and AlertMe systems which also operate using Zigbee, and the Aeon Labs series of Z-Wave Smart Switches.

The data monitoring setup (Fig. 2) comprises a low-power Raspberry Pi single board computer, running an Apache web server which dynamically accesses the SQL Database, enabling the monitoring interface to be viewed on any web enabled device or browser. Using a Raspberry Pi further gives the ability to use this system as a portable monitoring and remote logging device, which can be easily used in home and lab environments. It has been configured to automatically record to an SD memory card, upon detection of up to 10 Ploggs. Beyond 10 Ploggs, data collection at every second is impacted due to interference. Smart Home automation is being evaluated using a Z-Wave USB stick with multi-sensors which measure temperature, humidity, motion and light. Bridging software is being developed to allow the Z-Wave sensor to talk to the Zigbee based Ploggs, to turn them on or off based on sensed values and demonstrate protocol interoperability, and thus cross-automation. This is an example of multiple interface integration.

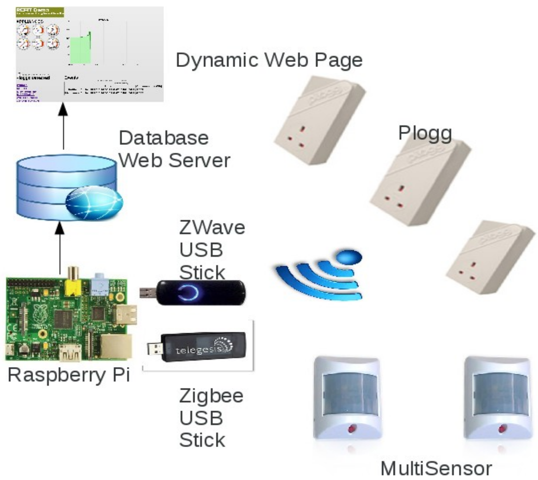


Figure 2: Monitoring Setup.

3.3 Initial Analytics

The benefit of collecting high resolution data is not only useful for building a NALM database, but such data can be used to analyse the performance of appliances. Appliance analysis can be used to evaluate the efficiency of appliances and to benchmark against those which have been rated as the most efficient. Furthermore, we can create useful models of appliances to estimate usage patterns.

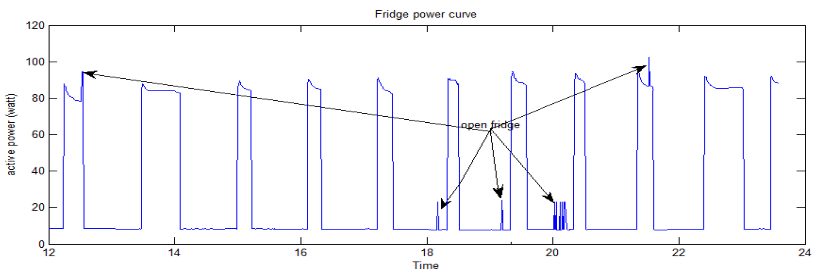


Figure 3: Fridge instantaneous power operation over 12 hrs, showing open door events.

Analysis further helps to characterise specific appliance use. Medium resolution data can be used to assess the operation of high-load, heavily used domestic appliances which may require servicing such as a refrigerator. Analysis will further determine whether the appliance is operating efficiently. For example, excessive consumption or frequent operation may indicate that the refrigerator coils need cleaning, or the positioning of the refrigerator is not optimal. Fig. 3 demonstrates regular consistent operation of a fridge from a 1 Hz dataset, which also shows when the door was opened, indicated by the short spikes in the graph, due to the switching on of an internal lamp. This type of data can also be useful for activity monitoring in assisted living applications.

4.0 Smarter Appliance: Kettle

The modern kettle is one of the most (inefficiently) used appliances. It requires a high power heating element to boil water, and is an appliance which is used daily during all times of the day, and can use three times the energy of a microwave [11]. Particularly, in office environments, it may be used many times and go through periods of boiling and re-boiling even though the water may still be at a suitable temperature for consumption of a hot beverage. Studies have shown that the heating element in a kettle is as efficient as it possibly can be [12], on average consumes between 2-3kW of electricity and the only ways of improving energy efficiency are to provide additional feedback about the amount and temperature of water, and for better insulation. This culminated in the design of the Kambrook Axis Kettle in 1997 [12], which had a number of energy saving features, including an easier to read water gauge and temperature indicator. Modern kettles now have these features, including the ability to boil to set temperatures; for example, to 80°C (recommended for tea) or 90°C (recommended for coffee).

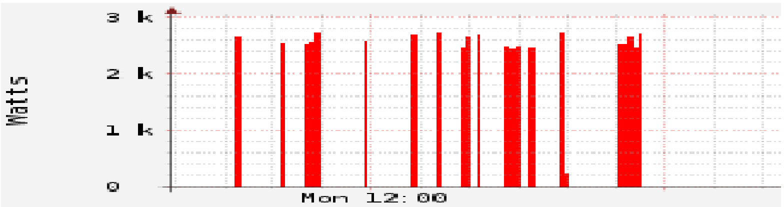


Figure 4: Kettle use from 9am – 5pm in a typical office.

In this paper, we aim to improve on these features by adding data connectivity so that information about the amount of water remaining and temperature can be communicated wirelessly while also being able to detect occurrences of re-boiling to estimate wastage. The impact of real-time sensing and analytics of the kettle operation could be felt for instance in an office setting with multiple users, where a kettle with a communications interface will enable remote and wireless alerting of remaining cups and temperature, while also providing the ability for remote activation of boiling. These features could save time, water and energy. Our motivation lies in the observation from data collected from our in-house direct monitoring and communication platform during a typical day in an office, as shown in Fig. 4 where we believe we could reduce re-boiling events due to frequent use at ‘peak’ times.

4.1 Experimental setup

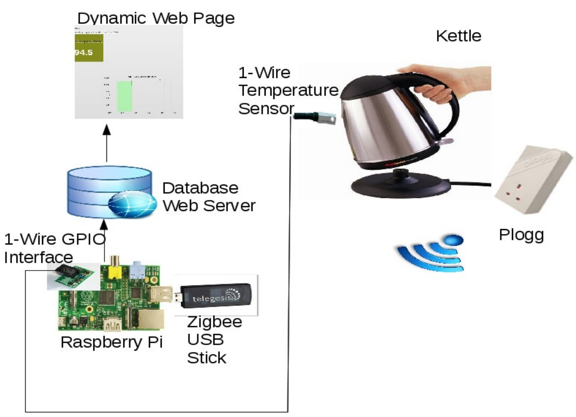


Figure 5: Kettle experimental monitoring setup.

We have created a model of energy consumption of the kettle, after closely analysing through experimentation, how it consumes electricity for various amounts of water. We can now use this model to estimate the amount of water that has been boiled, and further predict the consumption for various amounts of water and the initial start temperature. The start temperature will enable us to determine energy wastage through re-boiling. As shown in Figs. 5 and 6, a 1-Wire DS1820 digital temperature sensor has been placed inside the kettle to measure the air temperature, and interfaces to the Raspberry Pi using a Sheepwalk Electronics 1-Wire module. The sensor has been cased in aluminium to protect and water proof it, and is secured at the top of the kettle, essentially measuring the air temperature in the kettle. The volume of water is measured with generic kitchen scales, while the electrical consumption is monitored using a Plogg monitor. Data is collected by the Raspberry Pi, and stored in an SQL database every second.

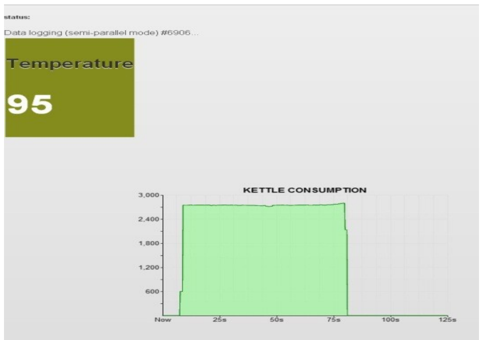


Figure 6: (a) Kettle Setup **(b) Kettle Monitoring Interface**

139 measurements were performed with different settings of water temperature and volume. After pre-processing, 24 incomplete measurements were discarded. Table 2 shows an example sample of our records from the dataset. Each row in the dataset relates to one measurement. The dataset consists of two subsets, one containing 103 records which are used for training, and the other subset contains 12 records which are randomly selected for testing.

Setting		Recording		
Water volume(ml)	Initial temperature (°C)	Effective power (W)	Duration (minutes)	Consumed Energy (kWh)
1000	64	2648	0.9	0.04
800	24	2635	2.1	0.09

Table 2: The sample of kettle data.

4.2 Data analysis

Using the training dataset to build the kettle model, the first step is to analyse the relationship between effective power, water volume, initial temperature, duration and consumed energy. Fig.7 presents the raw data curve for analysis. As shown in Fig. 7(a), the relationship between temperature and consumed power is nearly linear. Fig. 7(b) shows the relation between duration and the initial temperature. Comparing Figs. 9(a) and (b), we found that the duration is dependent on power consumption. So we only need to consider the power consumption to build the kettle model. From Fig. 7 (c), we can find that the duration of boiling time is linear with the consumed power and with different settings, the curve is lapped which means the effective power of kettle will not change under a different environment. Fig. 7(d) shows linear relationships, thus we will use linear methods to build the model.

In this experiment, we selected three classical linear methods to build the kettle model: polynomial linear, locally weighted linear regression, and the linear interpolation method. Residuals are differences between the one-step-predicted output from the model and the measured output from the validation data set. In here the residual is used to evaluate the degree of 'goodness' fit of the model.

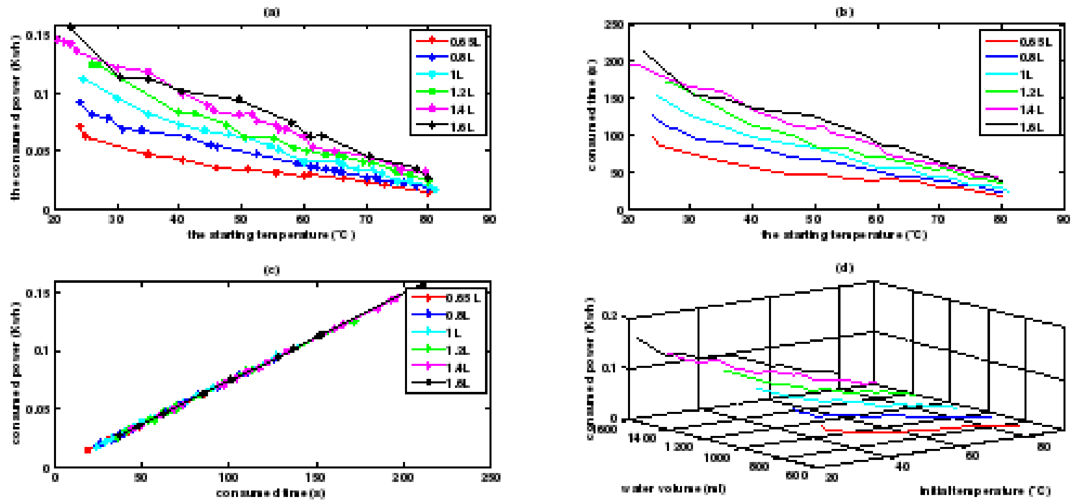


Figure 7: The kettle data curve.

Fig. 8 shows the three kettle models and the residual map of each model with the x-axis denoting the water volume, y-axis the initial temperature and z-axis the consumed energy The filled circle represents the collected data, while the coloured flat surface is the kettle model. Fig.8(a) is the prediction model of kettle built by the polynomial linear method. Fig.8(d) represents the residuals of polynomial linear model. As shown in Fig.8 (d), most of our training data is excluded in the linear model. Fig. 8(b) is the kettle model built by weighted linear regression method and the related residuals map is presented in Fig. 8(e). The interpolation model is shown in Fig. 8(c), and Fig. 8(f) is the residual data of the interpolation model. Note that there is only one residual data for the interpolation model. Comparing the residual map of the above three models shown, the best 'goodness' fit model for our training dataset is the interpolation model.

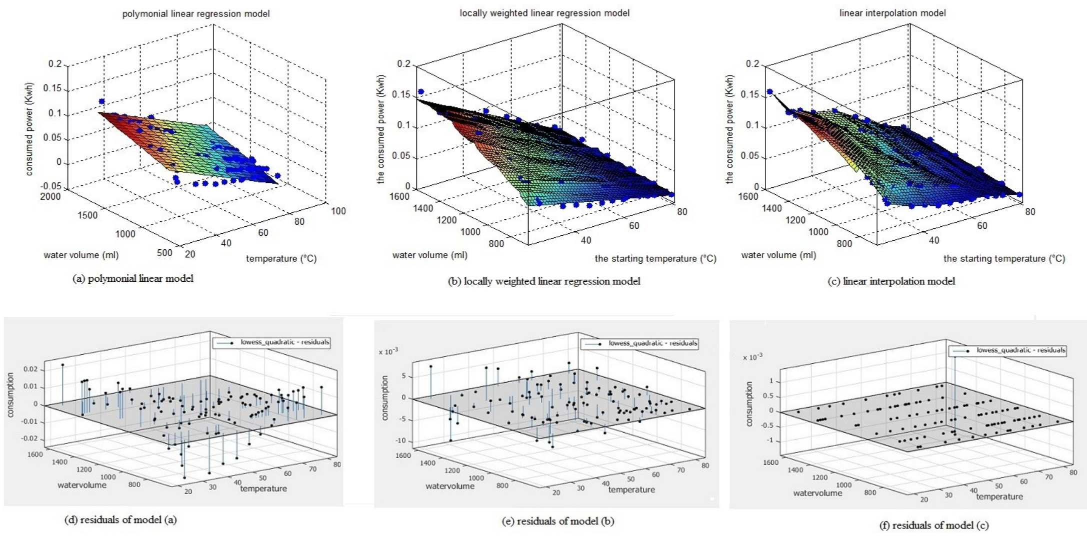


Figure 8: Kettle model and residual analysis.

4.3 Prediction

We applied the above three models in three ways: (i) predicting the consumed power based on the initial temperature and the amount of water in the kettle, (ii) predict the water volume based on energy consumption and initial temperature, and (iii) predict the initial temperature from water volume and consumption.

(a) Prediction of consumed energy

The first application of the kettle model is to predict the consumed energy. Table 3 is the estimated consumed energy by the three models. Model (a) is the polynomial linear model, Model (b) is the locally weighted linear regression model, and Model (c) is the linear interpolation model.

Consumed Energy (kWh × 10^{-2})	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**	**Test 10**	**Test 11**	**Test 12**
model (a)	12.56	6.28	4.81	5.22	1.47	11.31	7.66	5.20	6.04	2.47	3.27	3.68
model (b)	12.94	6.24	4.65	4.99	2.32	12.66	7.71	5.15	5.71	3.04	3.54	3.34
model (c)	NaN	6.16	4.46	4.76	2.46	NaN	7.57	4.84	5.54	3.06	3.49	3.61
Real	14.37	5.51	4.92	5.35	2.44	11.41	7.50	5.01	5.63	2.93	3.39	3.38

Table 3: The prediction results of consumption by three kettle models. We can see that the performance of model (b) and model (c) is better than model (a), but the model (c) misses two predictions out of 12 values.

Error(× 10^{-2})	Model(a)	Model(b)	Model (c)
Mean absolute errors	0.46	0.41	2.36
Squared absolute error	0.05	0.04	3.38

Table 4: The predicted errors of consumption from three kettle models.

Table 4 presents the prediction errors of the three models. Model (b) has the lowest mean absolute error and squared absolute error. Hence the locally weighted linear regression model (model (b)) can predict the consumed power correctly with a smallest error distance even though the interpolating model (model (c)) is a perfect fit to our training data.

(b) *Prediction of water volume*

The next application of the kettle model is to predict the water volume. Fig. 9 shows the prediction results for water volume of the three models. We can see that the performance of model (a) and model (b) is better than model (c). Table 7 presents the prediction errors of the three models. Compared to the three kettle models, the local linear regression model still outperforms the other two models.

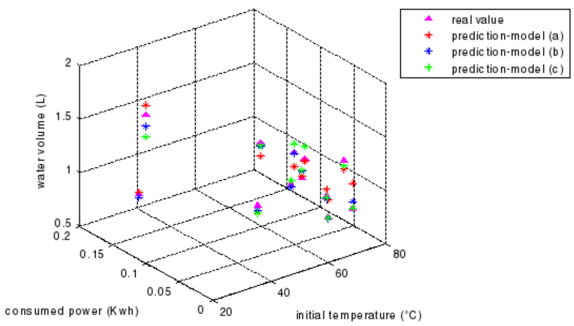


Figure 9: The results of water volume for test dataset using three kettle models.

Error(× 10⁻²)	Model(a)	Model(b)	Model (c)
Mean absolute errors	8.48	4.71	14.79
Squared absolute error	13.59	4.02	128.70

Table 7 The predicted errors of water volume from three kettle models.

(c) Prediction of initial temperature

The third application of the kettle model is to predict the initial temperature. Fig. 10 presents the prediction results for initial temperature of the three models. From Fig. 10, we can see that the performance of model (a) is the worst, and the model (c) still misses 1 prediction value out of 12 values.

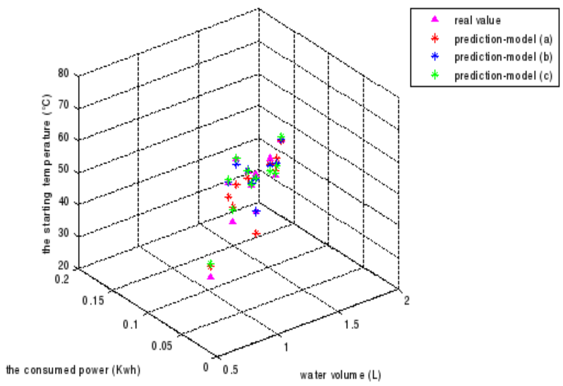


Figure 10: the results of initial temperature for test dataset using three kettle models.

Error	Model(a)	Model(b)	Model (c)
Mean absolute errors	3.06	1.35	3.98
Squared absolute error	178.30	46.24	928.40

Table 8 The predicted errors of initial temperature from three kettle models

Table 8 presents the prediction errors of the three models. The mean errors of model (a) is 3 °C which means the prediction error of model (a) is ±3°C, and the prediction error of model (b) and (c) is 1.35°C and 3.98°C, respectively. The locally linear regression model (b) gives the best performance. Through deeper analysis of the raw data, we find that the interpolation model cannot do the boundary prediction. All of the missing values are located at the boundary of the interpolation model.

5.0 Conclusions and Future Work

In this paper we have discussed and proposed energy monitoring methods in the context of smart home technology, and given an example of appliance monitoring and modeling to help improve appliance usage.

Our proposed system aims to integrate smart home automation, energy monitoring and data analytics on a single platform, which can provide decision support and efficient energy management of appliances in the home.

The study of the kettle model helps us to understand the relation between energy, water volume and water temperature. Comparing the three kettle models we built, the locally linear regression model is the best for the predictions. Based on the kettle model, we can now estimate how much energy is being consumed, how much water is being boiled to avoid instances of boiling too much water or re-boiling water activities to save energy.

Future work includes further development of data pre-processing or cleaning tools to make better use of measured data, and development of a complete decision support system tool with energy feedback disaggregation, which can advise on energy efficient appliance use and behaviour. This tool will be based on similar principles to the energy monitoring framework proposed in this paper. We will collect and analyse data from a sample of homes across the UK (Scotland and England) and will present the results which will identify energy consumption patterns and how these patterns relate with seasons, lifestyle and user behaviour.

We will also trial the connected aspect of our kettle in a typical office setting and quantify energy savings that can be made by providing additional information on energy use and communicated energy waste details through re-boiling. Other appliances under investigation include the refrigerator, and we intend to model the behaviour of various models and present the findings in a future paper.

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Where are the Smart Appliances?

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Abstract

'Smart appliances' have been just around the corner for over two decades. Why has 'smartness' made almost no impact on the global appliance market, unlike energy-efficiency, which is now mainstream? This paper examines why smartness in appliances is so elusive, and reviews recent developments which might finally bring us smartness we can use, not just smartness we can read about.

The main barrier to be overcome is the creation of a market, not the creation of technology. Electronics, communications and information technology has influenced appliance design just as it has other aspects of material life. However, appliances deliver familiar energy services such as heating, refrigeration and cleaning, which are best appreciated as the background of daily life, not the foreground. People generally want to use their smart phones and their increasingly scarce time to communicate with each other, not with their washing machines.

Buying more energy-efficient appliances brings immediate benefits, because buyers start to save money as soon they take them home and plug them in. The benefits of smart appliances are more problematic and contingent. While many countries have energy labelling and minimum energy performance standards programs, there is as yet no standard way to define smartness, let alone indicate degrees of smartness on a consumer-friendly label.

Several 'architectures' of appliance smartness have been developed in Europe, Japan, the USA and Australia, but none of them has made a major impression so far on its home market, let alone elsewhere. As long as the global market for smart appliances is poorly defined and fragmented, global manufacturers are reluctant to commit to it.

The means to overcome these barriers may finally be at hand. The enormous costs of expanding electricity supply in developing countries and maintaining aging grids in developed countries has raised the interest of utilities and policy-makers in alternative means of network management. The variability of renewable generation is also creating a need for a more responsive appliance load.

Advanced metering technology is offering clearer price signals as well as a means of communication. More flexible business models and regulations are allowing the costs and benefits of smartness to be shared between all parties. Finally, the IEC and other global bodies have started work on common standards for smart appliances.

What is a smart appliance?

The first problem in developing a market for smart appliances is that there is no accepted definition of a smart appliance. 'Smart' is one of the most over-used marketing terms of our time, taking its place alongside equally vague terms such as 'sustainable' and 'eco-friendly'. This allows appliance manufacturers to define 'smartness' as any attribute that increases the appeal of their products.

Some have used the term 'smart' for an appliance with a wider range of settings or options than its competitors, or with touch controls and digital displays instead of switches and knobs. Others have used it for products that combine functions and technologies in new ways. For example, a refrigerator may have a bar code reader to scan items going in and out and a screen that can display an inventory of the contents. The screen could also function as a television and as an internet portal for the kitchen, through which the user (or the refrigerator's own software) could place grocery orders.

This expression of smartness now seems dated. None of these functions is new, and most homes have computers, televisions, internet connections and even bar-code scanners that could do the same job. Even so, the combination into one device may save space, increase convenience and create new possibilities for the user.

Other manufacturers have equated smartness with the ability of users to control their appliances from outside the home, or to program sequences and combinations conveniently so that, for example, lights and appliances can be energised and de-energised with one command when the householder leaves home or returns, gets up or goes to bed - with different configurations for different situations. The 'Smart House' – in the terminology of the 1980s – encompassed all appliances and lights, as well as devices not currently electrified or automated, such as taps, curtains and windows.

Remote control is of course possible without integrated home automation. Once individual appliances such as televisions or air conditioners acquire remote controls, it is relatively straightforward to extend the geographic field of control outside the home. Indeed, several manufacturers already offer air conditioners with downloadable applications software ('apps') that allow internet-connectable mobile telephones ('smart phones') to mimic all remote control functions.[1] In some cases the final communications link to the appliance is made by the same WiFi router that connects many computers to the internet. Even so, is a remote control that is connected to the internet and works anywhere in the world really 'smartness'? Why not just programme the timer and thermostat before leaving home?

One constant in the development of smartness has been the attempt to link the leading edge technology of the time (e.g. electronics, automation, the internet, smartphones) to common appliances. Another theme has been the difficulty of creating a genuine market demand.

In 2012 the journalist David Owen wrote, in relation to smart appliances (which he considered an aspect of the smart grid, another poorly defined concept):

> 'Sometimes it's hard to believe that the smart grid isn't partly a marketing scheme devised by manufacturers. At the 2011 Consumer Electronics Show, I attended a seminar on networked appliances and realized – as the panel's members described the wonders awaiting homeowners savvy enough to upgrade to smart refrigerators, dishwashers and clothes dryers – that I'd heard it all before, and not just once. On my smartphone I searched the New York Times online and found an article that closely tracked the discussion in the seminar room…That article, by Joseph Giovannini, was published in 1988.
>
> …Because this was 2011, the main benefits for consumers were said to be energy savings, rather than Jetson-style convenience.[2] But the pitch was otherwise the same.' [1]

As the definition is so vague, we could say that appliances exhibiting some form of smartness have been around for a generation. However, they have made barely any impact on the global appliance market, despite decades of innovation, promotion and expectation. Takeup has been restricted to small groups of consumers who value novelty (the 'early adopters' of any new technology) and those who place special value on selected attributes such as out-of-home remote control.

This may be about to change, under the influence of the new metering technology, communications, appliance interfaces and novel forms of contracting between energy suppliers, demand aggregators and consumers (who may themselves be energy producers) – in other words, the 'smart grid'.

An emerging definition

Advanced metering technology allows electricity prices to vary not just between fixed 'peak' and 'off-peak' and 'shoulder' periods but at shorter intervals as well, up to the point where the change in price levels and time periods is flexible and continuous, ie 'dynamic'.[3] Appliances can be designed to

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[1] See for example http://www.samsung.com/au/air-conditioning/smart-zone/ and http://panasonic.co.jp/corp/news/official.data/data.dir/2012/08/en120821-9/en120821-9.html

[2] The Jetsons was an animated situation comedy program made for American television between 1962 and 1963. The Jetson family lived in a highly technological and automated home, set in 2056.

[3] Interval meters can record energy use during different time periods for the purpose of differential pricing, but are not necessarily 'smart'. While there is no standard definition, smart meters can generally:

- transmit the energy use data to the utility, so that meter readers are no longer required;
- receive and carry out commands such as disconnecting the supply when customers move out and reconnecting it when the next customer moves in;

respond to these changes by automatically modifying their operation. If this capability is deployed on a large enough scale, and if it can be called on with sufficient reliability, then the total economic investment required to maintain a high-quality supply of electricity is significantly reduced, and the resilience of the network in the face of peak demands and emergencies is enhanced.

The emergence of smart grids provides a new and sharper context for defining smart appliances. Up to now smartness in appliances has been seen as being of value primarily to consumers, and rather few consumers at that. If appliance smartness can create value for the electricity network as a whole, then all who use (and pay for) the network can benefit, not just those who own and use the smart appliances. Of course, consumers would have to accept some constraints on their freedom to use electricity but with sufficient planning, explanation, marketing and design for risk mitigation there is every reason to expect this could be achieved.

Linking smart appliances to the management of the network also means that the vast capital resources, revenues, pricing and marketing power of energy utilities can be brought to bear on promoting certain types of smart capabilities and so transforming the appliance market.

Some appliance manufacturers and industry associations have begun to make a distinction between 'connected' appliances, which are able to communicate with their owners or other appliances, and 'smart' appliances, which can also receive pricing or other information directly from or about the electricity network.[4] However, these distinctions are also unclear.

Connectedness and smartness should not be confused with any particular type of communications. Owners may access their appliances via GSM mobile phone system or the internet. Electricity networks have an even wider range of communication options available to them, including smart meters and power-line signalling systems such as ripple control, which may be just as effective for their purposes. It is entirely possible to have an appliance that is 'demand responsive' but communicates via pathways not accessible to the owner.

The following definition of a smart appliance was proposed in 2011 by the US Association of Home Appliance Manufacturers (AHAM) and the American Council for an Energy-Efficient Economy (ACEEE):

> 'The term "smart appliance" means a product that uses electricity for its main power source which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and automatically adjust its operation depending on both the signal's contents and settings from the consumer.'[2]

This definition has been incorporated into the 'Connected Product Criteria' proposed for the US Energy Star Product Specification for Residential Refrigerators, Eligibility Criteria, Draft 3 Version 5.0. [3] However, the terminology is 'connected', not 'smart' appliance.'[3]

The Australian and New Zealand Standard AS/NZS4755 *Demand response capabilities and supporting technologies for electrical products*, first published in 2007, does not use the terms 'connected' or 'smart', but 'demand response,' which it defines as:

> 'The automated alteration of an electrical product's normal mode of operation in response to an initiating signal originating from or defined by a remote agent.' [4]

Although there is considerable variation in terminology, there appears to be agreement that 'smart' capability in appliances consists of two key attributes:

- The ability to receive instructions from sources other than the user; and
- The ability to alter the mode of operation in response to those instructions.

- monitor the supply for faults and automatically advise the utility in case of problems;
- act as a 'gateway' or point of communications to the home for important information such as changes in price or notification of emergencies; and/or
- act as a two-way interface with the customer's own appliances via what is called a 'home energy network' or HAN.

[4] See for example http://blog.bosch-si.com/appliances-in-a-smart-grid-12-the-north-american-perspective/

These are the only agreed principles. There is a huge range in the possible pathways through which instructions may be received, their form and information content (e.g. when to start and stop the altered mode of operation, the type and degree of alteration required). There is also a wide range of design options regarding whether the appliance is limited to one specific communications system or can accommodate a range of systems with or without the use of add-on components.

The basic smart commands

The second key element of smartness, the 'ability to alter the mode of operation', can be broken down to as few as five basic instructions:

1. Turn off load, or go to least energy-intensive mode possible while maintaining essential ancillary services such as electronic controls or small fans and pumps;

2. Continue to provide the energy service which the product is designed to deliver, but at a reduced load or constrained level of operation;

3. Turn on load, even when user, timer or other controls would not normally call for energy;

4. Export energy stored or generated electricity to the grid, even when user, timer or other controls would not normally call for export; and

5. Do not export to the grid, even when user, timer or other controls would normally call for this.

Instructions 1 and 2 can apply to any appliance in principle, although further definition is needed before appliance manufacturers know exactly what functions to build in and test laboratories know how to verify them. For example, Instruction 2 can be expressed in a number of ways:

- In relation to the full output capacity or maximum operating load of the product;

- In relation to the average power (or energy used) over a given period prior to the receipt of the instruction (e.g. the last 5 minutes);

- As an absolute power level (e.g. no greater than 1 kW); or

- By prohibiting certain energy-intensive operations (e.g. defrosting in refrigerators or the use of resistance boosting elements in hybrid heat pump water heaters).

Basic instruction 3 – turn on load – only applies to products capable of storing energy or providing useful energy services without the user present. Examples include water heating, swimming pool pumping or electric vehicle charging. This can be of significant value when generation from variable renewable sources such as photovoltaics or wind is high. Switching on load at short notice may prevent the network operators disconnecting renewable generation sources, and so could raise the share of renewable generation that can be absorbed by a given network over the cycle of the year. Of course, a 'load-on' capability must be used carefully so that it does not lead to wasteful energy use – e.g. cooling or lighting buildings that are unoccupied.[5]

Instructions 4 and 5 obviously apply only to products capable of generating or storing electricity: batteries (both stationary and mobile, ie electric vehicles), and small scale distributed generators. At various times the network may require energy support – hence instruction 4 – or there may be local safety or over-voltage problems – hence instruction 5.

[5] The AS/NZS 4755 standard provides for a 'load-on' function for water heaters, swimming pool pump controllers and electric vehicle charge controllers, but not for air conditioners. As water heaters and electric vehicles store energy, the induced consumption displaces later consumption, so is not wasted. Where swimming pool pump operation is brought forward the controller must subtract the induced run time from the pre-programmed run time so there is no overall increase in pumping in any 24 hr period. As these limits do not usually apply to air conditioners it was considered that the risks of energy waste from switching them on remotely would exceed the benefits in terms of overall network management.

The Architecture of smartness

Both smart and non-smart appliance operation can be broken down to the same basis instructions. For example, the ability for users to load a clothes washer, select a wash cycle but delay the start by a specified period (or to a clock time) is already a common feature in products. The washer does not need to know the cause for the delay. It could be that the user does not want noise for a few hours, or wants to time the finish of the cycle so that they can hang out the clothes when they come home, or perhaps the home is on a time of use (TOU) tariff and the user wants the washing to take place during a period when calculate – correctly or not – that the cost of energy is lower.

The operation becomes 'smart' if the user specifies (or has previously specified) that the cycle should take place at a time when certain criteria are met, e.g. when electricity prices are low. But how does the machine know the price of electricity at any given time? It could receive the information from the meter, from the internet or other means, or perhaps it could simply be programmed in by the user. Most TOU tariffs have fixed time steps, which can be programmed in to standard interval meters (which do not have to be 'smart meters'). The actual price of energy at each time step, which may vary from year to year or even month to month, may not be known to the meter, but is applied by the utility only when it generates bills from the customer's interval usage data.

Actual price information is only necessary for the washer if it needs to calculate the amount of energy that can be saved by a delayed start, either to display that information as an added service to the customer, or to use it in a more complex way to overlay expected cycle times with price steps to optimise cost saving in some way. As wash cycle times are generally shorter that TOU price intervals, this is unlikely.

Therefore the 'architecture of smartness' can be constructed in a number of different ways. At the simplest, the user programs the machine with the tariff time steps – either on the machine itself or remotely via a smartphone or other device. Although this would not necessarily meet the first criterion of smartness (the ability to receive instructions from sources other than the user) it does meet the second criterion (the ability to alter the mode of operation in response to those instructions).[6] If the tariff happens to be low when the user presses start, the machine's logic controller allows the cycle to commence immediately. If not, then the controller effectively issues smart instruction 1 (turn off load) and later, when the clock time matches the 'low cost tariff' criterion, smart instruction 3 (turn on).[7]

Alternatively, the logic control could be located entirely outside the washer. It could reside in the software of a laptop or smartphone, a home area network, a smart meter or some other device. It could reside in the computers of the energy utility, the 'cloud' or a third party demand response aggregator. The logic control could be designed to integrate a vast range of information – not just tariffs, but whether the baby is asleep, whether so many high power devices are in operation that the clothes washer load could trip the home's load limiter, a weather forecast for good line drying weather or any other factors the user considers important enough to program in or arrange to be sensed. Some users may wish to monitor and act on information that is not communicated through the energy price, such as the level of renewable energy available to the grid.

In the end the controller needs only to communicate the same two instructions to the clothes washer: instruction 1 (no load) when the criteria for washing are not satisfied, and instruction 3 (turn on) when they are. However, in this architecture, there would need to be a physical pathway for the washer to receive information from the external controller. As clothes washers are not generally designed to receive information from external sources, this pathway (or pathways) would need to be defined. This is in fact the architecture adopted in AS/NZS 4755 (although the range of appliances covered by that standard does not include clothes washers).

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[6] Miele has designed a clothes washer that can accept user-programmed tariff schedules and also has the capability to later be connected to a communications hub to receive the information directly from outside sources. This product is described, accurately, as 'smart grid ready' rather than smart. http://www.miele-project-business.com/international/en/project_business/products/miele-at-home.aspx

[7] There may need to be other constraints – a user who has just missed the lowest cost period may not want to wait for 12-16 hours before the next one, and may settle for the next 'shoulder' cost period.

These examples represent two fundamentally different models of smart appliance architecture:

- A predetermined criterion for modifying product operation (in this case energy price) and the logic residing in the appliance (in this case a clothes washer); and
- No predetermined criterion, and the logic residing outside the appliance.

In fact there are many variations in smart architecture, combining aspects of both models. If some of the logic resides outside the appliance and some inside, this raises issues of communications protocols, message structures and priorities which require high levels of standardisation to resolve. This is not an insurmountable problem. It is analogous to the global standardisation which allows the internet to operate and for mobile phones to roam from one country to another.

However, it would require embedding information and communications technology (ICT) into appliances – perhaps to the point of assigning a distinct phone number and/or internet address to every product. While this is certainly possible, it may have a significant impact on the costs of appliances, especially if it forced lower-cost, lower-technology operators out of some markets. Alternatively, building a global smart appliance architecture on this basis may be of little value in developing countries, where the urgency of acquiring electricity load management capability is very high, if the necessary ICT platform does not extend to every house.

Who's in control?

There are legitimate concerns regarding the ability of appliance owners to influence the demand response process, and the risk that unauthorised persons or entities could exercise control over the operation of smart appliances or somehow exploit the information gained from their operation. One point of view is that users should always have the freedom to over-ride a demand response event. If the clothes washer does not start because it has been pre-set to wait for a lower price period, but the user wants the clothes washed straight away and does not mind paying a few cents more for the privilege, that is obviously their right.

This makes very little difference for clothes washing. Different households do their washing at different times of the day, so diversity is high. The power of washer motors is relatively low, and electricity use for water heating could range from high – where the user selects a hot wash and the water is heated in the machine – to nil, where the user selects a cold wash or the hot water is imported from a gas water heater.

Other appliances have very different characteristics. In Australia, the largest single contributor to electricity network peak demand is household air conditioning.[5] In most areas the last 10% of network capacity is used for less than 0.5% of the time, or about 40 hrs per year. If air conditioner load could be reliably reduced during those peaks, it would save billions of dollar of investment in the network – costs which have to be borne by all users, whether they contribute to the problem or not.

Although Australia has long had energy efficiency labelling and standards for new air conditioners and new buildings, where air conditioners are installed there is a 70% probability that they will be switched on during extreme peak periods, and most will be operating at maximum output without getting down to the thermostat set point.[6] The preferred air conditioner types are split units with internal thermostats, which makes it difficult to break into the control circuitry with after-market devices. Demand response strategies such as raising the set point of programmable communicating thermostats – which suits US air conditioner types and patterns of use, for example - are ineffective.

Nevertheless, trials have proven that even in the hottest conditions, customers will accept a reduction of up to 50% in the output of their air conditioner (ie smart instruction 2) provided the fan keeps operating and the period of output constraint is limited to about 2 hours. There will obviously be costs – room temperatures will be slightly higher during the control period than otherwise – but this is offset against enormous economic benefits.

It is estimated that in Australia the electricity networks need to invest an average of about A$2,900 of capital to provide a firm kW of capacity during summer peak periods. The average electrical load per installed air conditioner is about 2.1 kW during peak periods (even allowing for the fact that 30% of units will be off). Therefore contracting with users for the right to restrict their air conditioner load by

50% for no more than 40 hrs per year would reliably avoid about 1.05 kW of peak demand, worth over A$3,000 to the network.

This provides a lot of potential for savings to be shared between the network operators, the owners of the participating air conditioners (who may receive cash payments or lower tariffs) and with other network users. The potential can only be realised if users modify the way they use air conditioners. This could occur in three ways:

- If the price of using the air conditioner during peak periods is signalled to users at the time, they can make a decision about manually turning it on or off or setting it down. However, this requires both a time-variable price and a means of reinforcing the user's awareness of it at the right time. Time-variable prices have been available for many years but customers show an understandable reluctance to adopt them unless they are forced to.[8] If they do adopt TOU prices, in-home displays could amplify the price signal. None of this requires a smart appliance.

- Customers on TOU pricing who tire of having to respond manually could take advantage of the smart capabilities by programming their air conditioner to respond automatically when the price reaches a certain level. This is called 'price-driven demand response'. Users can decide to over-ride the response at any time, provided they are aware of when it occurs and are at home or able to control the product remotely. Any smart appliance should be capable of being used in this way, (although if the price information is programmed in by the user rather than conveyed directly from the outside world the arrangement would not meet the first criterion of smartness: the ability to receive instructions from sources other than the user).

- Customers could authorize their electricity utility or a demand response aggregator to control the cycling under agreed conditions. This is called 'direct load control'. The crucial difference is that no TOU pricing is necessary. Direct load control can work equally well under flat tariffs. The user's reward comes in the form of an up-front cash payment or a bill rebate, rather than as a saving in energy costs during high price periods. This allows the network to initiate demand response at times when the economic value to the network is greatest, which may be outside the pre-determined TOU price periods.[9]

In principle, smart appliance architectures should allow for either price-driven response or for direct load control, and for switching between them. However, the realisation of the economic benefit to the grid depends on the reliability of the demand response. In price-driven demand response, the network operators will have no idea of how many users have smart appliance capabilities, how many have programmed them to respond to price signals and how many will actually over-ride them during peak periods. Therefore the expected response must be heavily discounted and the potential to offer participation incentives will be limited.

In direct load control arrangements the network operator (or aggregator) has complete information on the number of households signed up and the product capacities and capabilities of each. If there is no over-ride button on the air conditioner, users cannot easily opt out during a demand response event. The costs may be higher than relying on price-driven response alone – not necessarily in extra equipment, since much of that would be required simply to communicate prices – but in marketing, incentive payments, call centres and data management. On the other hand, the economic benefits would also be much higher, because only through direct load control would demand response become large enough and predictable enough to factor into infrastructure planning.

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[8] One estimate is that by mid 2012 about 1% of US households had adopted TOU tariffs, despite almost every utility offering the option. http://blog.bosch-si.com/appliances-in-a-smart-grid-12-the-north-american-perspective/

[9] A more targeted form of TOU pricing is Critical Peak Pricing (CPP), in which the utility sends advance notice of a very high price periods (possibly several times the higher the highest step o the TOU tariff). These get a higher manual response rate than TOU prices alone, but represent risks for both the utility and the customer. As a high share of annual revenue is collected in a short time, small miscalculations in price levels by the utility and in the response by the user can result in disproportionate losses or gains. Indeed, a rational user would only enter such an arrangement with the protection of automated response or, better still, direct load control.

Whatever the model of demand response, consumers are ultimately in control. They can always choose not to purchase a smart appliance, not to activate its capabilities or to manage the response themselves rather than enter a direct load control contract . If they elect for a direct load control arrangement they would do so on the basis their own weighting of the risks (constraints on appliance use) and rewards (electricity bill savings or other incentives). Most countries have consumer protection legislation that require full disclosure of the conditions and which protect the vulnerable from being coerced into such arrangements. The elderly and households with members who are more sensitive to extreme temperatures would be advised not to sign up.

Customers who did sign up would have to be made aware that they could not over-ride an air conditioner demand response event simply by pressing a button – they would have to call a centre, and possibly withdraw from the arrangement permanently and forego the remainder of their benefits.

Smart appliances allow for a wider range of energy service business models and a wider range of pricing and contractual relationships between energy suppliers and their customers. If no customers want to take advantage of those possibilities, that is their right. But then, all users would have to incur higher electricity prices or the risks of blackouts flowing from lack of demand response.

Creating a market

The problem with smart appliances is not a lack of technology but the lack of a market. In fact the abundance of technological options is itself a barrier to the creation of a market. Users are not able to compare the advantages of different approaches and decide what is the best for them, or indeed if a technology has any value at all given their current electricity tariffs and communications options.

This is analogous to the situation with regard to energy efficiency claims in the period before governments mandated that all products of a given type had to be tested in the same way and the information reported in a common format, which is the legal basis of the existing energy labelling and standards regimes now in use in many countries.

This process is more complex for smartness, because the value of a given smart technology may be contingent on the availability of compatible supporting technologies (e.g. particular types of smart meters or home area networks), time of use tariffs or direct load control contract offerings from the local utility. A product which is smart (or can be made smart) in one utility service area may be just an ordinary product in the neighbouring area.

These uncertainties make it very risky for appliance manufacturers to build smart capabilities into their appliances, unless they know there will be a market demand, at least in some parts of the world. In fact, attempts are being made to create the conditions for smart appliance markets in several parts of the world. Up to now these attempts have been largely independent of one another, but the first steps are being taken toward some level of global convergence.

Perhaps the earliest initiative with a smart appliance aspect is the Japanese Echonet (Energy Conservation and Home Care Network), which was established in 1997. The Chairman of Echonet states:

> 'In the ECHONET Consortium, we have promoted the development of basic software and hardware for home networks that can be used for remote control or monitoring of home appliances. We have also established basic technology for the ECHONET Specifications. The aim in doing so has been to reduce CO_2 emissions while responding to the increasing sophistication of home security and home healthcare. The ECHONET Specifications are universal communication standards for linking home appliances made by different manufacturers and providing various services using easily installed transmission media, in both new and existing homes. They have also been recognized as international standards.'[10]

The first Echonet specification was published in 2000, and has been revised several times since. An Echonet Lite specification was published in 2011. The interest in using the Echonet standard to

[10] http://www.echonet.gr.jp/english/index.htm The appliance manufacturers supporting Echonet include Toshiba, Panasonic. Hitachi, Mitsubishi Electric and Sharp.

enable inter-operation between products from different appliance, home area networks systems and smart meter manufacturers has increased significantly since the earthquake and tsunami of March 2011 created long term disruptions in energy supply. A new Echonet Certification Centre was opened in November 2012. There has been no use of Echonet outside Japan so far, although as a result of participation in Echonet many Japanese appliance manufacturers have included basic demand response capabilities in some globally traded products, notably air conditioners.

Another initiative the smart appliance architecture is that embodied in Australian and New Zealand Standard AS/NZS 4755 the first part of which was published in 2007.[5] A technical specification for air conditioners was published in 2008 and revised in 2012. A specification for swimming pool pump controllers was published in 2012 and specifications for water heaters and electric vehicle charge/discharge controllers are due to be published in 2013.

The aim of AS/NZS 4755 is to give manufacturers all the information they need to build complying products. The standard specifies how an appliance should respond when it receives any of the five basic demand response instructions described earlier. It specifies a common physical and electrical interface (an RJ45 plug or a set of screw terminals) for connection of the product to an external demand response enabling device. This could be a smart meter, a Zigbee receiver, a ripple control receiver, an internet-connected device or any other. The appliance manufacturer does not have to know which. The architecture was deliberately designed so that the smart capabilities of the appliances could be used with virtually any communications device, either in a price-driven demand response environment where the user has sole control or under direct load control arrangements.

By August 2012 some 53 of the 1,160 air conditioner models registered for sale in Australia had an AS/NZS 4755 interface built in, and a further 178 models could comply with the addition of a standard interface card.[11] This included both imported and locally made models. The Department of Climate Change and Energy Efficiency, which manages the national appliance standards and labelling program, has indicated the intention to mandate compliance with AS/NZS 4755, so that all new air conditioners and other covered products sold after a date yet be determined must have an interface, subject to a national cost-benefit analysis and regulation impact assessment.[6]

Although it is expected that most appliances will never have their interfaces activated, the measure is still justified if the net community benefit is high enough and the benefits are widely distributed through lower network charges for all. This is the principle on which many countries have mandated energy labelling. Even though many appliance buyers pay no attention to the label when they buy an appliance, the presence of the label gives them the option to do so, and all buyers – including non-users of the label – benefit from the increase in appliance efficiency stimulated by labelling.

In the USA, interest in demand response and smart appliances was stimulated by the Energy Independence and Security Act of 2007 and by the American Recovery and Reinvestment Act of 2009, which contained about US$3.5 billion in funding for smart grid projects, including some that test and deploy smart appliances.[7]

In 2011 the Association of Home Appliance Manufacturers and the American Council for an Energy-Efficient Economy petitioned the Environmental Protection Authority to request ‘a five percent credit to the energy performance level required to meet Energy Star eligibility criteria for smart-grid enabled appliances’.[2] In other words, appliances with this capability were to qualify for the Energy Star endorsement despite using up to 5% more energy than would be required for ‘non-smart’ products of the same type.

The EPA agreed to this proposal and developed criteria for what it calls ‘connected’ appliances in the Program Requirements: Product Specification for Residential Refrigerators, Eligibility Criteria, Draft 3 Version 5.0.[3] The proposed implementation date is currently March 2014. EPA has also started work on connected appliance criteria for air conditioners, but these are not yet complete and no start date has been announced.[12]

[11] Some of these models are listed http://www.energex.com.au/sustainability/sustainability-rewards-programs/households/energy-conservation-communities-ecc/whats-involved?a=76902

[12] https://www.energystar.gov/products/specs/node/170

The EPA has indicated that it is including this allowance as a way of 'helping to "jump start" the market for refrigerators with smart grid capabilities', and definitions and rules for connected appliances could change over time.[2]. It is understood that there is no plan to have a special version of the Energy Star label for appliances that meet the 'connected' criteria.

The European effort on smart grids is led by the three organisations CEN (the European Committee for Standardisation), CENELEC (the European Committee for Electrotechnical Standardization) and ETSI (the European Telecommunications Standards Institute). The aim is an integrated set of standards for smart grids, smart houses and smart appliances although the preferred term for 'smartness' in appliances is 'demand response'.[8] CENELEC has published a Roadmap for 'SmartHouse and related systems' which states that:

> 'The technical requirements for the Roadmap that follow from the project's purposes are:
>
> - Help manufacturers from industries to ship their products to a consumers home where they will be interoperable and provide services sharing resources by recommending a limited and helpful set of international (European) standards
> - Advise consumers who want to access services in- and outside the home on appropriate standards
> - Recommend a minimum of (existing) standards and specifications that fit in a common architecture providing seamless communication in and outside the home
> - Assure that standards reach a higher level of interoperability instead of the whole market having to move to one particular standard'.[9]

As there are as yet no European standards for appliances which meet the criteria, there are none on the market, although some European manufacturers are offering products that they term 'smart-grid-ready'. The European standardisation effort is also closely linked with the International Electro-Technical Commission (IEC), which has set up a number of committees related to smart grid standards. The most relevant to smart appliances are:

- PC 118 Smart Grid User Interface (set up at the request of the China National Standards Committee, first met in February 2012);
- TC 57 Power systems management and associated information exchange; and
- TC59 Working Group 15 Connection of household appliances to smart grids and appliances interaction (first met in October 2012). This is the IEC body responsible for developing a global set of standards for smart appliances. It has representation from the National Standards Committees of Italy, Germany, Japan, China, Turkey, the USA and Australia.

To date, China has not developed its own smart appliance standards, preferring instead to take part in the IEC process. Some Chinese appliance manufacturers use the term 'smart' in their marketing, but the products so described are not capable of demand response, so do not meet the criteria for smartness proposed in this paper.

Legally smart

To date, no country in the world has succeeded in creating a market for smart appliances, but the ones most advanced are the USA, Australia and Japan. While they are using different technical and policy approaches, they share a critical principle – definitions of 'smartness' that are specific, testable and hence legally enforceable.

As it happens, none use the term 'smart' in the documents that define smartness. The US EPA uses the term 'connected', the AS/NZS standards use the term 'demand response' and Echonet specifies command structures for changing appliance operating status. Whenever the attributes of 'smartness' are analysed and stated to the level of precision required for standards, more precise terms become necessary.

The ideal basis for developing a global market for smart appliances would be an accepted international standard. Governments could then allow appliances to called 'smart' (or any other agreed term) only they comply with the standard in question. This analogous to the requirement that statements about appliance energy efficiency to be made in relation to specified energy test.

However, the benefits of a smart appliance can only be realised once it becomes part of a system of technical elements that allows it to receive information from or about the outside world, and part of commercial arrangements which reward the user for allowing the appliance to modify its operation in some circumstances. The linking technologies (e.g. home area networks, connectors, smart meters) would also need to be compatible with the appliance standards, and labelled as such.

An over-arching set of standards that covers all possible elements of such a complex system may well be impossible, despite the efforts of the IEC. The best achievable outcome may be a set of smart appliance standards covering a limited number of generic technical categories, for example:

- Products that have internal communications capabilities and those that do not;
- Products capable of two-way communications and those restricted to one-way communications (ie receiving instructions but without confirming receipt or action);
- Products that require the presence of specific elements such as smart meters (themselves complying with standards yet to be defined) and those which do not;
- Products that are capable of being controlled only by the user (and hence have smart value only in the context of TOU tariffs) and those capable of participating in direct load control arrangements.

The main drivers of demand for smart appliances are likely to be electricity utilities and related service providers such as demand response aggregators. Communications pathways and commercial contracts are likely to differ significantly between countries. businesses, network regions and service areas. While these can never be standardised, it will be of great value to the development of demand response programs if utilities can refer to legally verifiable published standards when offering customers or manufacturers incentives for the promotion of smart appliances in their areas.

Conclusions

So where are the smart appliances? Until we agree what the term means, we cannot answer this question. 'Smart' is one of the most popular marketing terms of our times, and until now one of the most vague. We can bring some clarity by defining what is not smartness. Appliances capable of being accessed and operated by their user remotely using smartphones or over the internet are not necessarily smart. Appliances do not have to be energy-efficient to be smart, and smartness does not necessarily make them energy efficient.

Although there is considerable variation and confusion in terminology, 'smart' capability in appliances appears to consist of two key attributes:

- The ability to receive instructions from sources other than the user; and
- The ability to alter the mode of operation in response to those instructions.

These capabilities allow the appliance to interact directly and automatically with the electricity grid, and so contribute to the dynamic balancing of supply and demand which is one of the key objectives of the smart grid.

There is a huge range in the possible pathways through which instructions may be programmed or received, their form and information content (e.g. when to start and stop the altered mode of operation, the type and degree of alteration required). There is also a wide range of design options regarding whether the appliance is limited to one specific communications system or can accommodate a range of systems with or without the use of add-on components.

Smart capability can be realised in a vast number of ways and under a vast range of business models - some involving only the appliance owner and some involving electricity suppliers, aggregators or other service providers, acting with the agreement of the owner. Some arrangements involve smart metering and response to changing electricity prices, but some do not. In some business models the utility which gains the economic benefits of controlling a smart appliance (through not having to build as much supply infrastructure) will return some of the benefit to the smart appliance owner as an up-front or recurrent incentive payment. Thus smartness creates both new forms of economic value and new ways to share that value between appliance owners, electricity suppliers and other stakeholders.

One of the keys to encouraging smartness (as it was for energy efficiency) is technical standardisation. Manufacturers must know what to build, and smart products need to be able to realise commercial value in many different utility service areas and under many different electricity pricing and regulatory regimes. While at present there is little prospect of agreeing on the means of communicating with smart appliances, standardisation of smart response is now possible. Any system or arrangement that can transmit five basic instructions – load off, reduce load, load on, store energy and discharge energy – is capable of achieving smartness in virtually any appliance.

Several national and now international standards bodies are working towards this objective. However, given the diversity of approaches and requirements globally, a single common standard may well be impossible, and the best achievable objective may be a series of standards – hopefully limited in number and linked by some common elements – related to different 'smart architectures'.

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Energy Efficient Products and Smart Homes

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Abstract

The electricity sector is changing rapidly as we are moving from fossil fuel centralized power stations towards a more distributed and smarter electricity network. The electricity supply must be secured while also lowering the carbon emissions. Smart grid technologies offer the possibility to meet these challenges and develop a “cleaner”, more efficient and sustainable energy system enabling also the wider penetration of renewable energy sources. Demand Side Management enables the control of energy exchange between consumers and energy utilities, focusing on the reduction of demand peaks. In this paper we explore the effects of using energy-efficient products and the use of Time Of Use (TOU) pricing on the total energy use, the energy costs for the consumer and the peak-power demand of the house.

We have developed an analytical model which simulates the total homes’ energy consumption for specific appliances’ use-profiles. The model is built up bottom-up and is composed of different consumer appliances which each have their own power-profile. Three scenarios are investigated and compared the Business As Usual (BAU) benchmark, a standard house without energy-efficient consumer electronics and without any smartness. The first scenario is the Energy-Efficient scenario, where the house is equipped with appliances using Best Available Technologies (BAT). Smart control is introduced in the Smart-TOU scenario, where the effect of TOU pricing on the power demand is investigated. In order to study what would happen if there was a limit in peak power we have simulated the Smart-Peak scenario, where a household does not exceed a certain power threshold during peak-time periods.

The results of the simulation show that a great reduction in energy usage and peak power demand can be achieved when the electrical appliances in a household are replaced by more energy efficient products without compromising on the users’ comfort. When smart-controlling is applied a drop in peak power demand is shown of respectively 40% and 50% compared to the BAU scenario. As expected the energy-reduction of both smart scenarios are not significant compared the energy-efficient scenario, but a significant decrease in peak power can be achieved when a certain maximum power threshold is introduced. Unfortunately this does not significantly show a reduction in the users’ energy-costs for the household in the specific case simulated, which makes it questionable if there is incentive enough for the household to introduce smart-shifting of appliances.

Introduction

The electricity sector is changing rapidly as we are moving from fossil-fuel centralized power stations towards a more distributed and smarter electricity network. Smart grid technologies offer the possibility to meet these challenges and develop a “cleaner”, more efficient and sustainable energy system [1] enabling also the wider penetration of renewable energy sources. In the Netherlands, through smart grid concept, the objective is to reduce energy consumption as well as greenhouse gas emissions [2].

Smart house integration where automation systems are installed monitoring intelligently the daily living of the consumer and its energy use derives as a necessity from the significant changes that the electrical system will foresee while transforming to a smart grid. Smart houses changes the role of the current home, turning it into a more “autonomous block” in a smart grid [3]. That means that the users in a household can decide themselves about their consumption and/or production and with whom they exchange. Electricity consumers not only become more aware of their consumption and relevant subjects, but they also accept a wider installation of smart meters and technologies [4]. The efficiency and sustainability of smart homes is fully exploited through Demand Side Management (DSM), improving in this way the management of the total power grid and enabling the higher penetration of distributed generation.

Smart grid development leads to several emergent technologies each with different impacts on the market [3]. End end-user feedback can help enabling consumers to monitor their energy demand, be informed whether local green energy production is available, at what rate, and to get tips for further reducing energy consumption. The automated decentralized control of distributed generation combined with demand response enables better matching of energy demand and supply conditions. This can be achieved by stimulating users to accept demand management, for example the rescheduling of some of the appliances or other loads, whether this is pre-programmed by themselves or controlled by an external agent. One of the incentives for the consumer to react to this external agent and change its behaviour is lower market prices of electricity. Within this paper we want to investigate if the introduction of smart appliances acting on TOU tariffs will lower the total electricity use and costs of a single household.

A model is developed which generates a household-load profile based on different appliances with their own power profile, and a randomly selected operation time of the appliance. With this generated load profile different strategies decreasing energy- and power-usage are evaluated and compared. A simple home energy management controller is designed which effectively shifts appliances based on total power consumption, pricing variations, user prioritized needs and overload management. This house model forms the basis for testing smart grids in combination with sustainable energy-sources for residential areas, for instance on the island of Vlieland in the Netherlands.

Relative work

Demand Side Management (DSM)

Demand side management includes a number of methods to control the exchange of energy between consumers and suppliers and adapt the power production to the user energy needs. It also focuses on the reduction of demand peaks, which add a significant cost in energy production. According to Long Ha et al. [5] there are two basic forms of DSM: one form is aiming at a direct control of appliances' loads, by cutting off directly those requesting high power or, in other words, by absorbing the sudden variations in demand which cannot be supplied efficiently. This type of DSM is called "emergency DSM". The other form is the "economical DSM", which includes the encouragement of consumers to shift the energy from peak hours to off-peak hours providing financial incentives. With these forms the peak periods are reduced or shifted during the day.

Clastres [2] claims that when additional information about their usage and not just an energy bill is provided to consumers, a reduction of up to 20% in energy consumption can be achieved, consequently leading to significant cost savings. It is claimed that this number comes to 5-15%, while the reduction achieved when just looking at the energy bills ranges between 0-10% showing how low the benefit is when only the consumption status is provided to consumers [6, 7]. When dynamic tariff is applied, energy saving can reach 14% of the consumption. This percentage is twice that of the saving which can be achieved when only meters are adopted [2].

Because of the complexity of the electrical system, the total management and control can be divided in three layers interacting with each other via information flows [5]. The higher level is the load management layer, responsible for the dynamic control of the energy consumption of all the houses, adjusting an upper limit by taking into account customers' feedback and also capacity constraints of the production. The next level is the home automation level, which consists of the Home Automation Systems (HAS) of all houses. A HAS manages the predictions about future user requests and available resources, as well as the variation of market prices. Lastly, the appliance layer, characterized by the fastest dynamics, includes all the appliances and their embedded controls and is responsible for the real-time distribution of energy by taking actions of control like enabling and disabling certain appliances. At this level, the home energy management is one of the current issues nowadays in the market, and maybe the most interesting and promising, since the consumers are trying to save from energy bills and they are encouraged to reduce their consumption not only for decreasing the capital cost for production, but also for limiting the use of fossil fuels the energy of which, mostly goes for generating electricity [6]. Home management systems enable households and utilities to monitor all the appliances, which are connected to each other and to the entire system, control them even remotely and conserve energy. Combined with smart grid technologies, like smart meters home energy management can make us rethink about energy and its usage.

Time Of Use (TOU) Tariffs

Dynamic energy pricing schemes enable the user to decide how and when to use their appliances. Although there might be some people motivated by environmental friendly feelings, most are motivated by economic benefits. Thus, it is really important for the utilities to offer tariffs that can encourage consumers to shift their usage and rethink their daily use habits.

Time Of Use (TOU) tariffs can stimulate consumers to change the use of some appliances by shifting their operation to time periods when rates are lower and of course saving money. The smart appliances respond automatically to utility signals either by shifting the load to non-critical times or “spreading” it, which means extending their operation for longer time and lowering the power demand. Of course the utility, since the appliance cycle will be longer, must reassure that consumer will have an economic benefit for the total cycle [8].

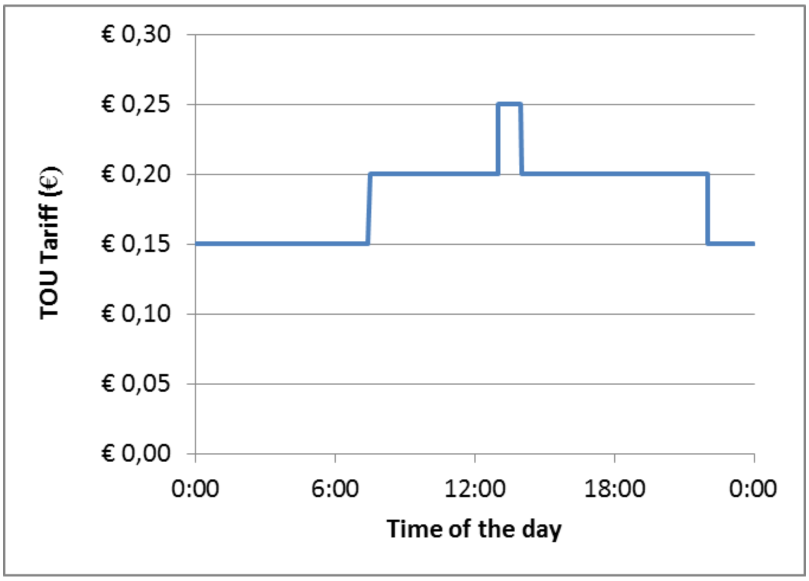

Figure 1: Example of a 3-level TOU tariffs.

According to Stromback et al. [9] a possible scheme of TOU tariffs can include two levels of price, peak and off-peak prices, but there might be also a third level called “partial peak” or “shoulder” level as shown in Figure 1. Peak prices coincide with the time interval where the peak demand of the day appears. Therefore, consumers try to avoid this time period and shift their consumption to earlier or later hours. Furthermore, the TOU tariffs can vary depending on the day and season but consumers should always be aware of them in advance

Models for generating load profiles

Many models have been developed to predict load profiles because of their importance in research of distributed generation and demand side management. Capasso, et al. [10] present a method for load generation based on demographical, socioeconomic data, different functions for the set of appliances involved and probability factors to analyse consumer’s consumption behaviour influenced by psychological and behavioural factors. Montecarlo process was used and the approach followed includes two basic steps: the aggregation of individual appliances in order to derive the household load profile and then the aggregation of all the load profiles to extend the model for more houses. However, the measured data used had been taken with 15 minutes time interval.

More recent Paatero et al. [11] used a bottom-up approach where statistics and public reports consist the source for many data needed. The consumption data generated are on an hourly basis while the model makes use of statistical averages and representative samples to overcome the lack of detailed and real data. However, DSM strategies like shifting the appliances to a later time or cutting off the operation of appliances in case of emergency where included for deriving the main demand curve. Novel methods such as generic algorithms and neural networks as well as fuzzy logic are suggested when little information is available about the appliances [11].

Gottwalt et al. [12] have developed a household model where the households are equipped with smart appliances and for which the consumer is charged based on time-based tariffs showing an interest in estimating the potential savings, the investment cost for the additional equipment but also for the amount of load that can be shifted and the peak load that can appear.

Armstrong et al. [13] and in a similar way Esser et al. [14] present a model for the development of which statistical data for the annual power consumption but also probability distributions were deployed. The load curve derived is generated under flat tariffs and then differences in the price for different times of the day are introduced to test the results from load shifting and consumer's response.

Yao & Steemers [15] suggest that the load profiles should be based on residential occupancy and seasonal factors and these methods are mainly based on average household profiles.

This paper proposes a model of a house which generates load profiles by aggregating the appliances in the house and enabling their shifting according to a 3 level TOU pricing scheme, allowing at the same time for different energy reduction approaches and the extension of the model for a wider area or community to be studied.

Design approach and Analysis

The model simulates the impact of energy efficient products and demand side management on the daily energy consumption and the costs of that for a single household. First a study was conducted to examine the potential energy conservation, when energy-efficient appliances replace the existing and less efficient ones in a household, the effects of Best Available Technology (BAT) versus Business As Usual (BAU). Second a simplified home controller was designed in Simulink™ which was used to explore how a home energy management system would contribute to more flexible energy use taking into account the individual consumption profiles of the appliances, the tariff rates and overload management. Technical possibilities such as peak shifting or clipping are inserted in this way, enabling to study what the effects of these scenarios are for the consumer.

The BAU benchmark is considered as a reference scenario depicting the existing trends in households and the energy market, while assuming their continuation in the future. It is also assumed that the structure of the system will be the same for the coming years as well as the consumer's demand behaviour and of course without any reduction in comfort. The houses in this scenario are equipped with a large variety of appliances with only a few of them being highly energy efficient and of the latest technology. Three scenarios are benchmarked against BAU:

1. **Energy Efficient scenario**: using only Best Available Technology (BAT) energy-efficient appliances, at least A-label appliances replace the older less efficient ones in the household. Furthermore three appliances - the dishwasher, the washing machine and the dryer - are chosen not to function at will but only during the low-tariff off-peak time periods (semi-automation).
2. **Smart-TOU scenario:** which uses the BAT appliances together with feedback about TOU tariffs. This scenario focuses on encouraging consumers to change their behaviour. This can be done by giving them feedback about their consumption so they can shift the operation of some appliances to periods when prices are lower. In the model it is assumed that the consumer is willing to change its behaviour based on changing tariffs.
3. **Smart-Peak scenario** where peak shifting and clipping is introduced, by limiting the maximum peak-power consumption of the household [16]. The overload threshold consumption, however, is determined via feedback and information exchange between the supplier and the household.

Modeling the controller

Load Profile generation

The focus of this paper is on developing a model of a house's electricity-use using a predefined load profile based on 25 appliances, and benchmark the different strategies to the BAU scenario. The model was simulated in MATLAB/Simulink just like in [17, 18, 19]. Simulations are performed which help in comparing the energy consumption between the BAU scenario and the Energy Efficient and the two Smart scenarios. Some characteristics of the house model implemented and the inputs that are introduced are summarized and presented later on.

In general the daily load profiles are characterized by power spikes from the different appliances. Averaged data, on the other hand, tend to "lose" information because of the large time intervals they sometimes insert, leading to a considerable reduction in resolution or smoothens out the peaks giving the impression of a low (power) and more constant electricity profile. A typical household may be equipped with 10 up to 60 different appliances, each with its own characteristic and load pattern or use pattern. The household load profile used in this paper is derived from the aggregation of 25 individual appliances (see Table 1). Each household appliance has a unique load profile, which is represented as a pattern. In Figure 2 the load pattern of a three appliances are depicted, the dryer, the dishwasher and the washing machine. The rated power of both the BAU and also the A+ energy-efficient appliances are presented in Table 1, which are collected after a market research.

Table 1: 25 appliances and attributes used for load generation and there rated power.

Appliances	**Power (W) BAU scenario**	**Power (W) EE/Smart scenario**	**User Priority**
Washing machine	2284	1102	3
Dryer	2756	828	3
Dishwasher	1600	807	3
Vacuum cleaner	2200	1250	2
Microwave	1700	900	1
Kettle	3000	2200	1
Laptop	100	50	1
Desktop	300	50[1]	1
Toaster	1000	1000	1
Coffee machine	1000	1000	1
Electric shaver	13	13	1
Hair dryer	1500	1500	1
TV 40"	180	63	1
TV 32"	79	42	1
Food blender	500	500	1
Hob	3000	3000	1
Oven	1400	900	1
Iron	2000	2000	2
Freezer	110	48	1
Refrigerator	90	40	1
Lighting	30-562	30-360	1
CD player	100	60	1
Printer	200	45	1
Phone charger	3.5	4.5[2]	2
Standby of laptop	15	8.9	1

[1] The desktop is assumed to be replaced by a laptop computer in the energy-efficient and the smart scenario's.

[2] This value is higher than the BAU value because of the higher power consumption while charging new phones as smartphones.

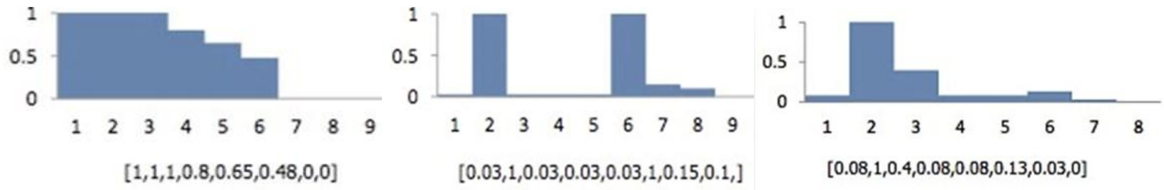

Figure 2: Load patterns for three household appliance, the dryer, the dishwasher and the washing machine, as a percentage of the rated power versus the time in steps of 15 minutes.

Table 2: Level TOU Tariffs used in the house model simulated

	Time period	Tariff (€c / kWh)	percentage per day
Off-peak time period	00:00-07:29; 22:00-23:59	15.00	40%
Shoulder time period	07:30-11:59; 14:00-21:59	20.00	52%
Peak time period	12:00-13:59	25.00	8%

Smart shifting of appliances and control strategy

Nowadays the user prepares the home appliance and after asking for a program, the appliance starts. In smart houses this is not always the case. In both the Energy Efficient and Smart scenario's the user is also asked to set the latest time during the day that he wants the appliance to end its operation. When the user asks for an appliance to operate, the Smart Home Controller (SHC) checks the current market tariff and depending on the appliance's priority level (1, 2 or 3) either it loads the appliance or delays it untill the conditions for price and priority over previously requested appliances are met.

The priorities are set according to user's preference and apart from describing the urgency and consumption needs, they facilitate the shifting to the right price level. For this work, the priorities used for the appliances are based on different previous approaches that can be encountered such as in [16]. The priority numbering is used only in the Energy Efficient scenario, where only priority 1 or 3 appliances are used, and in the Smart Scenarios, where also priority 2 appliances are introduced. The shifting of appliances is based on three different price levels: peak, shoulder and off-peak hours pricing, see Table 2. To be more specific:

1. Priority 1: Appliances that will/have to operate on demand. No shifting is allowed
2. Priority 2: Appliances operate only during off-peak and shoulder periods, like the vacuum cleaner, the iron and the phone charger. The ones that are loaded during peak hours are advised to shift to the first allowed level in the order of appearance first in first out.
3. Priority 3: Appliances which are used only during off-peak hours, like the washing machine, the dishwasher and dryer unless the user has set a prior desired finishing time.

Priority 1 appliances have priority over priority 2, which in turn have priority over priority 3 appliances. In every case, priority 1 describes those appliances that need to be loaded on request, even if there is no "room" below the power threshold. The appliance needs to wait for the total consumption to be restored under the acceptable power limit. The user can set the latest time that he desires the appliance to end and if the appliance is not loaded by that time, the appliance skips the shifting and it is loaded at the end of that margin. Switching off the appliances while operating is not always desirable, so, this is not an option in the simulation model. Different control strategies are incorporated in the controller for the simultaneous request for operation of several appliances. For example, if more than one appliance at the same time and with the same priority are asked by the consumer to operate, the SHC enables the one with the higher power demand to be loaded first. However, it is unlikely that more than one or two appliances start at the same time.

Main Characteristics

Based on the analysis presented in [20] the main characteristics of the house model can be distinguished:

- It is event driven, meaning that it interacts in a dynamic way with the user's request for using an appliance. The controller decisions are based on the power level and price at the moment of request. If the time is appropriate for the appliance to be used or it needs to be delayed till a later time in the day when conditions of usage will be met.
- It takes into account the market prices. The controller shifts the appliances according to the price level that can be provided by the energy provider. It can be understood that the price levels can change from time to time, since the cost and availability of varies, especially for renewable sources
- Time varying signals: Power level showing the peak load demand, consumption profiles of the appliances, and price levels vary during the day. Load limits could also vary according to local renewable sources or in-house generation, for example. However, more variation in pricing and load limits can also be considered.

Results

Business as Usual (BAU) scenario

In Business as Usual (BAU) scenario where most of the appliances in the household are of low energy efficiency, the daily household load curve simulation is shown in Figure 3. According to the load curve depicted in the figure the peak power demand is 6228W while the daily energy consumption is estimated to be 20.1kWh. The energy bill that the consumer has to pay to the energy utility, according to the given TOU tariffs, as described in Table 2, the energy consumed will cost the household around 4,33 €/day.

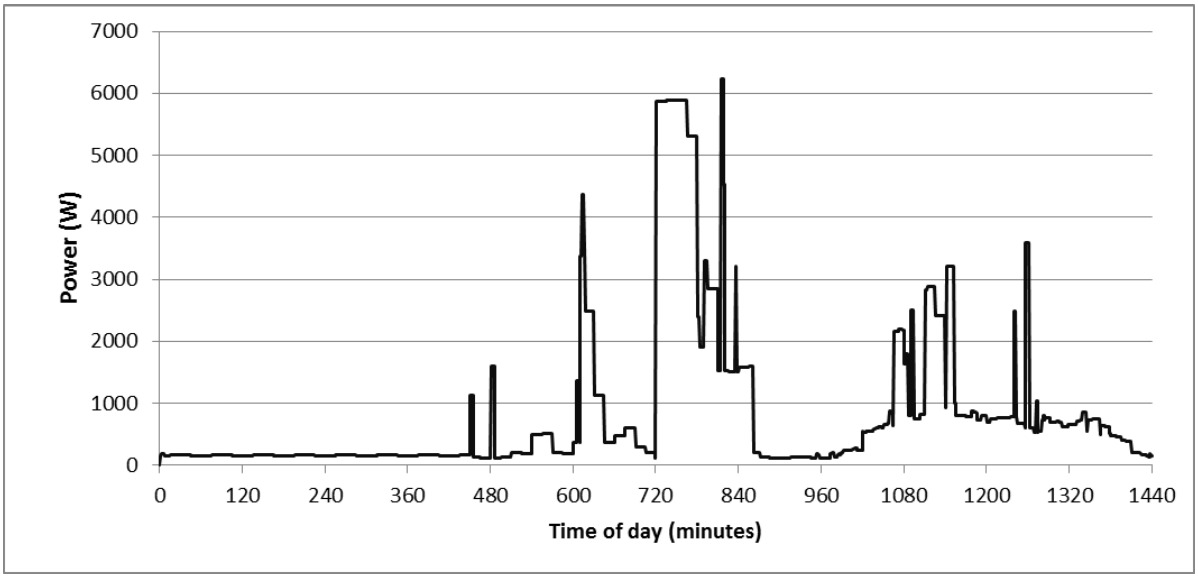

Figure 3: Daily load profile for benchmarked BAU scenario.

Energy Efficient Scenario

In Energy Efficient Scenario the appliances are replaced by energy efficient ones and semi-automated appliances which can be shifted in time (priority 3). The scenario also opperates without loss of comfort. A significant reduction in the daily demand curve can be observed in Figure 4 where the line represents the resulted load from the Energy Efficient scenario and the dashed line the load curve from the BAU.

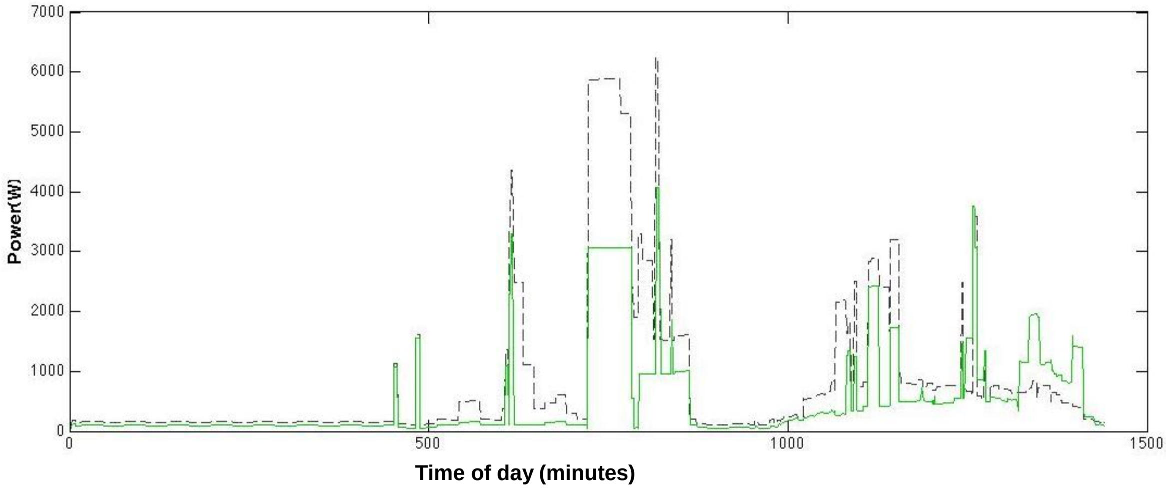

Figure 4: Daily load profile for the Energy Efficient Scenario compared to the BAU benchmark.

The load curve presents an outstanding daily reduction in energy used from 20.1kWh to 12.3kWh (39%), while the peak power was reduced to 4066W (35% of that of the BAU), mainly caused by the lower consumption of the electrical equipment and to a lesser extinct by shifting the semi-automated appliances. Also a significant drop was observed in the energy bill, which was found to be 2.54 €/day, almost 41% of that of the BAU, which could be appealing to the consumer to shift to BAT appliances.

Smart-TOU scenario

For the first smart scenario, the consumer's contribution is necessary in order to reduce the energy consumption and peak power demand. The *Smart-TOU scenario* demonstrates how the Smart Home Controller plans smart appliances (and appliances equipped with smart sensors and smart plugs) starting times based on economic savings (lower operation cost). This is achieved by loading each appliance according to priority number and the first in first out waiting order. So appliances characterized by 2 or 3 priority number are shifted to off-peak hours, instead of being loaded at high-cost peak hours. Figure 5 represents the resulted load from the Smart-TOU scenario compard to the Energy Efficient scenario.

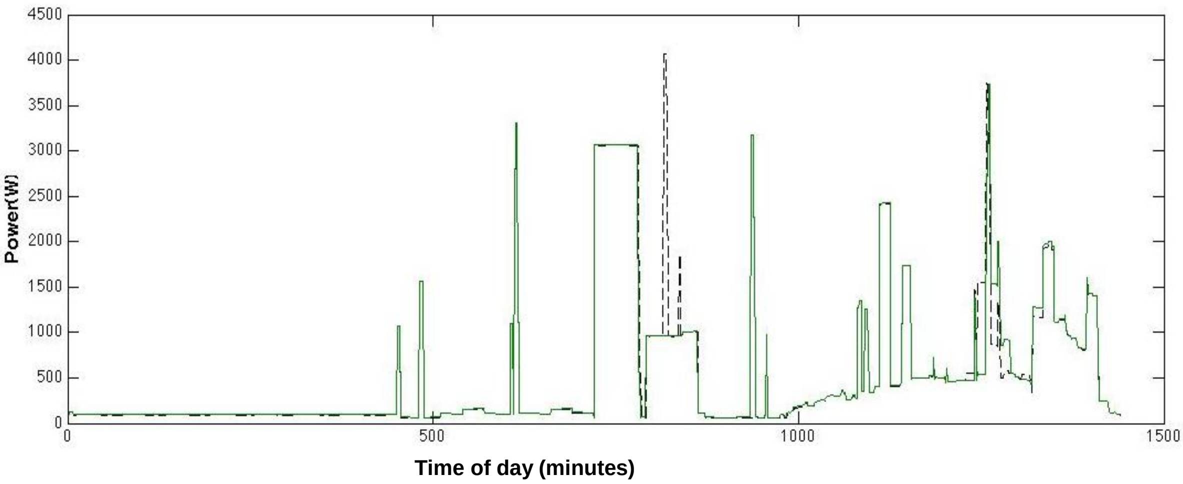

Figure 5: Daily load profiel for the Smart-TOU Scenario compared to the Energy Efficient Scenario.

As expected the total energy consumption does not drop below the energy-consumption of the energy-efficient scenario (12.3kWh). However, since the home controller is now responsible for the efficient and cost-effective management of the electrical equipment, the power demand dropped to 3734W, which equals to 40% of BAU. The total energy costs are estimated to be 2.52€ er day, 42% of BAU, which barely shows a reduction compared to the energy-efficient scenario.

Smart-Peak scenario

In the second smart scenario a 3700W power threshold is introduced together with the TOU tariffs as for the Smart-Peak scenario. Here, the simulation shows how the system allows the appliances to be loaded according to the lower execution cost, while assuring the overload management.

The results from the calculations show that the peak power is reduced to almost 3100W, 50% of the BAU scenario, despite the high threshold limit equal to 3700W (just below the maximum of the smart-TOU scenario). This can be explained, since some of the appliances that were to be loaded would exceed the power threshold if added to the total system's power and is thus shifted to a low-power region. Despite the reduction in the peak power there is no significant cost saving compared with both the Energy Efficient as the Smart-TOU scenario. What is more, a delay between the two load curves presented is observed. This is because the integrators used in the model hold the priority "queue" and the total consumption of the house every sample time, adding a quite remarkable delay in the load profile generation.

Table 3: Results overview of the different scenario's.

	Energy consumption [KWh/day]	Peak load [kW]	Energy costs [€/day]	Reduction in Energy use [%]	Reduction in peak load [%]
BAU	20.146	6228	4.33	-	-
Energy Efficient	12.285	4066	2.54	39%	35%
Smart-TOU	12.285	3734	2.52	39%	40%
Smart-Peak	12.285	3107	2.53	39%	50%

In Table 3 an overview is given of all scenario's compared. Based on this test it shows that energy-efficient appliances will introduce a great reduction in the energy-consumption for households. Other "smart" appliances only introduce a reduction in the peak load, and not significantly in the total energy costs. It must be taken into account this simulation was only based on one on/off

Discussion and conclusions

In this paper we have designed a model which is used to evaluate the potential for reduction of the total energy consumption of a household by introducing energy-efficient appliances and smart control of some of the appliances. The smart home controller was able to effectively control the appliances taking into account the pricing tariffs provided and the feedback received, associated to the prioritized needs set in the model and the total consumption level signals.

Although the simulation results look quite promising, only when more user-profiles and more specific appliance' load-profiles are inserted in the model the true potential of these efforts can be revealed. The model developed can be considered as a showcase, which aims to demonstrate the influence of the scenarios evaluated.

A significant reduction in energy use and peak power can be achieved by replacing the existing appliances with more energy-efficient ones, and by introducing shifting the time of use of washing machines, cloth dryers and dishwashers, allowing their latest possible end times to be set. The energy savings were 39 % of BAU, while the peak power demand dropped by almost 35%.

In both the Smart-TOU and Smart-Peak scenario the peak power reduced by 40% and 50% respectively, compared with the BAU benchmark, while energy savings and the energy costs remain about the same as in the Energy Efficient scenario. The results of the calculation indicate that introducing smart shifting in houses does not give any incentive for the user to introduce this level of smartness into their own home. Introducing it will contribute to lowering the peak-power load of the grid, and to give the user incentive to reduce its peak-power he/she should be rewarded for it, for instance, by lower connection fees.

Recommendations

To underpin the preliminary conclusions the model has to be evaluated with more randomized use-scenario's where every application is used within certain time bandwidth or even excluded from the list based on penetration percentage. After producing this large amount of load-profiles different TOU tariffs settings can be evaluated and optimized for low peak-power load and/or the tariffs can be optimized for low total energy-costs for the home.

Low peak-power houses are not only interesting for larger utilities but also for smaller energy-initiatives at district level where sustainable energy is introduced in combination with temporarily energy storage. Lower peak-power and a more distributed energy consumption over the day will decrease the amount of costly power generators (like PV cells) and temporary storage systems (like batteries).

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Smart Home System: Integration of Energy Facilities and Environmental Factors

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Abstract

This paper proposes a power smart home system to manage and coordinate electricity consumption of household appliances and local power generation with consideration of the status of smart grid, weather forecast, and occupants' activities plan. The smart home system orchestrates electricity facilities and environmental factors to achieve an overall financial benefit. The proposed smart home system is a central point to manage and coordinate energy related activities at residential homes. It has the capability to take the advantage of the variable price of a smart grid and maximize the benefit of local power generation. It supports occupants of residential homes to reduce electricity cost by scheduling and rescheduling consumption of household appliances with running flexibility. The system architecture is presented with details of communication network, data storage, and system modules. The proposed architecture provides a solid foundation for evolving smart home system in its implementation in the reality.

1. Introduction

Smart home technology targets residential buildings with facilities and devices that can communicate with each other and perform a variety of tasks with "ambient intelligence" [1,2]. It covers extensive technical advances that can bring intelligent features for homes in response to residents' needs in terms of management for energy efficiency, services for comfort and convenience, provision of home-based healthcare, and assistance to elderly or disabled people etc. In this paper, we focus on energy-related smart home technology with highlights on renewable energy sources [3], smart electronic appliances [4], smart grids [5], and robust forecasting and monitoring [6] of environmental factors.

As renewable energy sources such as solar power and wind grow fast as a percentage of overall power supplies, smart grids have become a promising means of the integrated management of electricity demand and supply. Smart grids technologies focus on digitally enabled electrical grid that collects, analyzes, and acts on information according to dynamic status of both suppliers and consumers in order to improve the efficiency and reliability of electricity services. Most of existing research of smart grid targets the achievement of decentralized coordination for networks of planners and controllers. The power supply and demand are considered at a coarse granularity level without considering the details of energy usages and renewable energy sources of individual homes.

Smart appliances utilize modern computer and communications technology to make functions faster, cheaper and more energy-efficient. The smart appliances can take advantage of an energy "smart grid" and contribute to load management in future energy systems with larger shares of renewable energy. Most of initiatives and proposals about smart appliances emphasize individual appliances with new capability to adapt smart grid technologies. It is still lacking of solutions to consider the complex relationships of multiple appliances, local renewable energy resources, and environmental factors.

Most of existing building energy management systems or software focuses on commercial buildings. These systems are designed for the automated control and monitoring of those electromechanical facilities in a commercial building which yield significant energy consumption such as heating, ventilation and lighting installations. The emerging technologies of smart home appliances and renewable energy sources from residential homes are beyond their concerns.

The residential homes are undoubtedly one of the main energy consumers. Existing solutions consider the power supply and consumption at a coarse granularity level where the details of smart appliances, sustainable energy sources, and environmental factors have not been taken into account.

The emerging technologies of sustainable energy sources, smart appliances, electricity sub-meters, and accurate monitor and prediction of environmental factor are summoning a robust solution with sophisticated consideration of the complex and complicated relationships of appliances, renewable energy sources, and external power suppliers. It is highly necessary to develop innovative models and frameworks which have the capabilities to manage and coordinate power consumptions and sources with the support of emerging technologies of ubiquitous computing, sustainable energy sources, smart appliances, electricity sub-meters, and accurate monitor and prediction of environmental factors. A scheduling scheme has been proposed in our previous work [7] for smart home electricity management.

In this paper, we propose a power smart home system as a central point to manage and control electricity consumption of household appliances and local power generation in the context of smart grid. The proposed system can help home occupants to easily manage and control devices and activities related with electricity consumption/generation and reduce electricity cost of a residential home. The proposed solution collects real data of electricity consumption and generation in the residential home and uses the collected historical real data to help the scheduling of electricity consumption and generation at the residential home. The system architecture will be presented with details of communication network, data storage mechanism, and system modules.

The paper is organized as follow. Section 2 discussed assumptions and the context of power smart home management. Section 3 presents the system architecture for power smart home management with details of communication network, data storage, and system modules. Section 4 provides the description of day-ahead static scheduling and runtime rescheduling of electricity consumption and generation at a residential home. Section 5 overviews some related work. Section 6 concludes this paper.

2. Power Smart Home Management

This section discusses the context of power smart home control and management and provides an example of electricity facility and household appliances at an Australian residential home to illustrate the research motivation of this work.

2.1 Residential Homes on Smart Grid

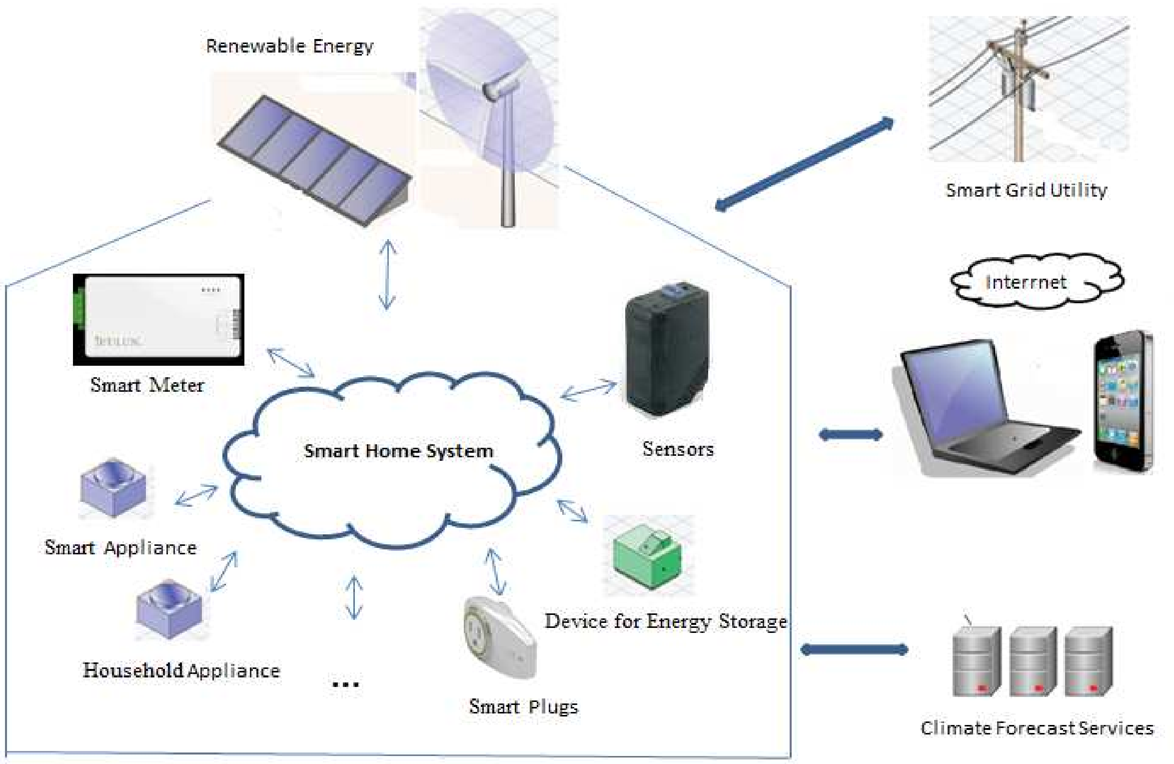

Fig.1. Power Smart Home System

Figure 1 shows the target smart home system in the context of smart grid and local renewable energy resources. The residential home is linked with smart grid utility to buy or sell electricity power. Home occupants can monitor and control home electricity facilities through computer and/or smart phones over the Internet. The residential home has local renewable energy resources, electrical appliances, and energy storage. Some of electrical appliances may be smart appliances which can provide power consumption forecast for each requested program and/or be able to adjust power consumption behavior to take the advantages of smart grid. The sensors can help to monitor the home environment and provide evidences for further control and management. The smart meters are able to collect and provide electricity consumption data at the home. Smart plugs can provide on/off control and power sub-metering for appliances that are connected to. The smart home system will combine ubiquitous computing and centralized computational intelligence to help home occupants manage electricity related activities and dynamically interact with home electricity facilities. There are the following assumptions for the smart home system targeted in this research:

- The residential home is connected with a smart grid that is capable of bidirectional power flow and has varying electricity price.
- The residential home has renewable electricity resources such as solar PV and wind turbine which are dependent on environmental factors such as weather conditions.
- The residential home has a set of household appliances that consume the electricity. The electricity consumption of these appliances are dependent on predictable occupants' behavior and environmental factors such as weather conditions.
- Home occupants have full control of their own electricity consumption and local electricity generation.
- Some requested electricity consumption has a degree of flexibility such as flexible time frames of execution.
- Home occupants have the access of the smart home system to monitor, schedule, and control electricity facilities at the smart home.
- Environmental factors are available, for example, local weather forecast is accessible.
- It may have smart plugs, sensors, and smart meters to monitor and control power related activities at the residential home.

2.2 Electricity Facility and Household Appliances

This subsection provides an example of residential home in an independent house at Australia with a set of electricity appliances. It is assume that the residential home is linked with a smart grid and it has solar PV as its local electricity resources. In order to give readers some ideas of possible quantitative facts, the specifications with real figures rather than generic description of smart grid, solar PV, and household appliances are provided.

The smart grid utility has a variable electricity price for selling power to residential home. Here the "PowerSmart Home" plan [8] of Energy Australia is assumed to be the tariff scheme of the smart grid. The Peak time is 2pm - 8pm on working weekdays with use tariff 52.5470 cents/kWh. The Shoulder time is 7am - 2pm and 8pm - 10pm working weekdays and 7am - 10pm on weekends and public holidays with use tariff 21.3400 cents/kWh. The other time is off peak with use tariff 13.0900 cents/kWh. It is almost sure that electricity tariffs of the future's real smart grids will be more dynamic than above tariffs according to different time-periods.

A solar photovoltaic system with 3kW peak output is installed at the residential home and it is the only local renewable energy resource. Due to the existence of local electricity generation by solar PV, there is chance for the home to sell power to the smart grid. In this work, it is assumed that the price gap between buying and selling power from the smart grid is a constant value as 5cents/kWh.

As an example of a typical residential home in Australia, it is assumed to have multiple household appliances which are connected to the smart grid with smart plugs. A ZigBee Panel Meter from JetLun

[9] is installed at the residential home. With the help of smart plugs, the smart meter has the capability to collect and provide energy consumption data of individual household appliances. Some of these appliances may have running flexibility based on specific constraints. These appliances are connected to smart plugs and can be switched on/off by commands from smart home system. More details are:

- There is a dishwasher with power 1.5kW. The washing time is 40 minutes. As default, the starting time is flexible but dishwashing task must be completed in the specified 24 hours period.
- Swimming pool pump is used for poll maintenance with 1.1 kW power. The swimming pool pump will run 8 hours as total each day. As default, it can run at multiple time periods with constraint as that each period must be at least one hour This must be completed in the specified 24 hours period.
- An automatic washing machine runs with 500 W and cloth dryer runs with 3kW. The washing time is half hour. The dryer running time is 1 hour. As default, it can have a flexible starting time and the cloth washing and drying should be consecutive activities.
- There is a central air conditioning system with maximum power 3kW. The air conditioning system runs according to climate conditions and occupants' requirements.
- There is a smart electricity refrigerator/freezer with 400 W. Normally, this energy consumption is not affected by the target energy management.
- There is a range of electrical lamps that are switched on/off according to lighting requirements of home occupants.
- There are other electrical devices such as TVs, computers, alarms, etc. These devices run according to occupants' home activities.

3 System Architecture

The details of electricity facility and household appliances in a typical Australian independent house have been provided in last section as a motivation example. This section presents the system architecture for power smart home management to deal with the motivation example. The proposed solution for power smart home management will be under a centralized architecture. The household appliances, local renewable energy generators, smart grid utility will be connected by the home network and controlled by smart home system. The smart home system also has the capability to get information from weather services and receive messages from remote computers and smart phones for home occupants to control or monitor the status of local power generation and electricity consumption by household appliances. The smart home system has the capability of static scheduling and runtime rescheduling for electricity consumption and local generation at a residential home to minimize the total cost of electricity power while satisfying power requirements. The communication network, data storage, and system modules will be described in this section.

3.1 Communication Network

The smart home system needs to communicate with devices/services outside or inside the residential home. The communications between smart meters and smart grid utility will be supported by the Wide Area Network of the smart grid. The Internet technology is employed to enable the communication between the smart home system and applications on computers/smart phones and weather services. At the residential home, it is not necessary to have a home area network with a wide bandwidth for high communication speed. Communication needs between smart appliances, smart plugs linked with household appliances, local power generators, sensors, smart meter, and the smart home system can be handled with low cost, low power, low data rate, and short distance technologies such as IEEE 802.15.4 - ZigBee, IEEE 802.15.1 - Bluetooth, IEEE 1901 - HomePlug. As a wireless mesh network, ZigBee has a high reliability and low cost deployment capabilities; in particular, it is convenient to interface with smart metering and smart appliance purposes. In the proposed power smart home system, ZigBee is employed as the home networking solution.

3.2 Data Storage

A permanent data storage mechanism is crucial in the development of power smart home system. The power smart home system aims to reduce the electricity cost at a residential home by scheduling the power demands according to a rich set of power related data that describe the dynamic status of smart grid, local power generation, energy consumption of household appliances, sensor data, weather data, and occupants' activity data. A "PowerDB" database implemented by MySQL is proposed to store these data and support queries from the smart home system. The "PowerDB" takes the responsibility as the central point for electricity related information at the residential home to be collected, organized, and searched.

Smart Grid: "*Smart_Grid_Tab*" is the table in "PowerDB" for smart grid related data. It has data fields "*time_point, tariff, current, voltage, power_consumption*". The data is collected by the installed ZigBee Panel Meter with time interval of 15 minutes.

Air Conditioning: "*Air_Conditioning Tab*" is the table in "PowerDB" for data of air conditioning. It has data fields "*appliance_id, time_point, on_off, mode, current, voltage, power_consumption, temperature_setpoint*". The air conditioning data is collected with time interval of 15 minutes.

Swimming Pool Pump: "*Swimming_Pool_Pump_Tab*" is the table in "PowerDB" for swimming pool pump data. It has data fields "*appliance_id, time_point, on_off, mode, current, voltage, power_consumption*". The data is collected by the installed ZigBee Panel Meter with time interval of 15 minutes.

Dishwasher: "*Dishwasher_Tab*" is the table in "PowerDB" for dishwasher data. It has data fields "*appliance_id, time_point, on_off, mode, current, voltage, power_consumption*". The data is collected by the installed ZigBee Panel Meter with time interval of 15 minutes.

Washing Machine: "*Washing_Machine Tab*" is the table in "PowerDB" for washing machine data. It has data fields "*appliance_id, time_point, on_off, mode, current, voltage, power_consumption*". The data is collected by the installed ZigBee Panel Meter with time interval of 15 minutes.

Cloth Drier: "*Cloth_Drier_Tab*" is the table in "PowerDB" for cloth drier data. It has data fields "*appliance_id, time_point, on_off, mode, current, voltage, power_consumption*". The data is collected by the installed ZigBee Panel Meter with time interval of 15 minutes.

Refrigerator/freezer: "*Refrigerator_Freezer_Tab*" is the table in "PowerDB" for refrigerator/freezer data. It has data fields "*appliance_id, time_point, on_off, mode, current, voltage, power_consumption*". The data is collected by the installed ZigBee Panel Meter with time interval of 15 minutes.

Electrical Lamps: "*Electrical_Lamps_Tab*" is the table in "PowerDB" for electrical lamps data. It has data fields "*appliance_id,, time_point, on_off, mode, current, voltage, power_consumption*". The data is collected by the installed ZigBee Panel Meter with time interval of 15 minutes.

Other Devices: "*Other_Devices_Tab*" is the table in "PowerDB" for other devices data. It has data fields "*appliance_id, time_point, current, voltage, power_consumption*". The data is collected by the installed ZigBee Panel Meter with time interval of 15 minutes.

Weather Observation: "*Weather_Observation_Tab*" is the table in "PowerDB" for weather observation data. It has data fields "*local_date_time, air_temperature, relative_humidity, cloud, delta_temperature,wind_dir,wind_spd_kmh, dew_ point*". The data are obtained from broadcast service of weather observation on the Internet [10]. The time interval is 10 minutes.

Weather Forecast: "*Weather_Forecast_Tab*" is the table in "PowerDB" for weather forecast data. It has data fields "*local_date, cloud, sunrise_time, sunset_time, air_min_temperature, air_max_temperature, relative_humidity, wind_dir, wind_spd_kmh, dew_point*". The time interval is 3 hours.

Temperature Sensor: "*Temperature_Sensor_Tab*" is the table in "PowerDB" for sensor data. It has data fields "*time_point, sensor_id, location, measure_value*". The time interval is 15 minutes.

Home Calendar: "*Home_Calendar_Tab*" is the table in "PowerDB" for home calendar data. It has data fields "*calendar_item_id, date, date_type*".

Schedule: "*Schedule_Tab*" is the table in "PowerDB" for scheduling details of electricity consumption and generation data at the residential home. It has data fields "*schedule_id, calendar_item_id, schedule_details*". The "schedule_ details" includes detailed running mode, start time, and end time for each household appliance with running time flexibility.

3.3 System Modules

The power smart home system manages the power consumption at a residential home in order to reduce the cost of household electricity consumption by considering the varying power tariff of smart grid and predictable local power generation. The proposed system will take into account of a rich set of data about smart grid, local power generation, power consumption of individual household appliances, weather conditions, measured properties by sensors, and occupants' activity plan. The power smart home system collects these data and save them in the "PowerDB" database described in last sub section. The power smart home system has the interfaces to get control commands of home occupants from appliance controllers and/or applications on computer/smart phone. The smart home system will make the schedule for local electricity generation and consumption at a residential home. The smart home system will perform event-driven dynamic rescheduling according to dynamic power supply, local generation, and operations of household appliances. The smart home system will perform real time control on solar PV, household appliances, and sensors. The development of the power smart home system follows a typical object oriented design with multiple classes shown in Figure 2.

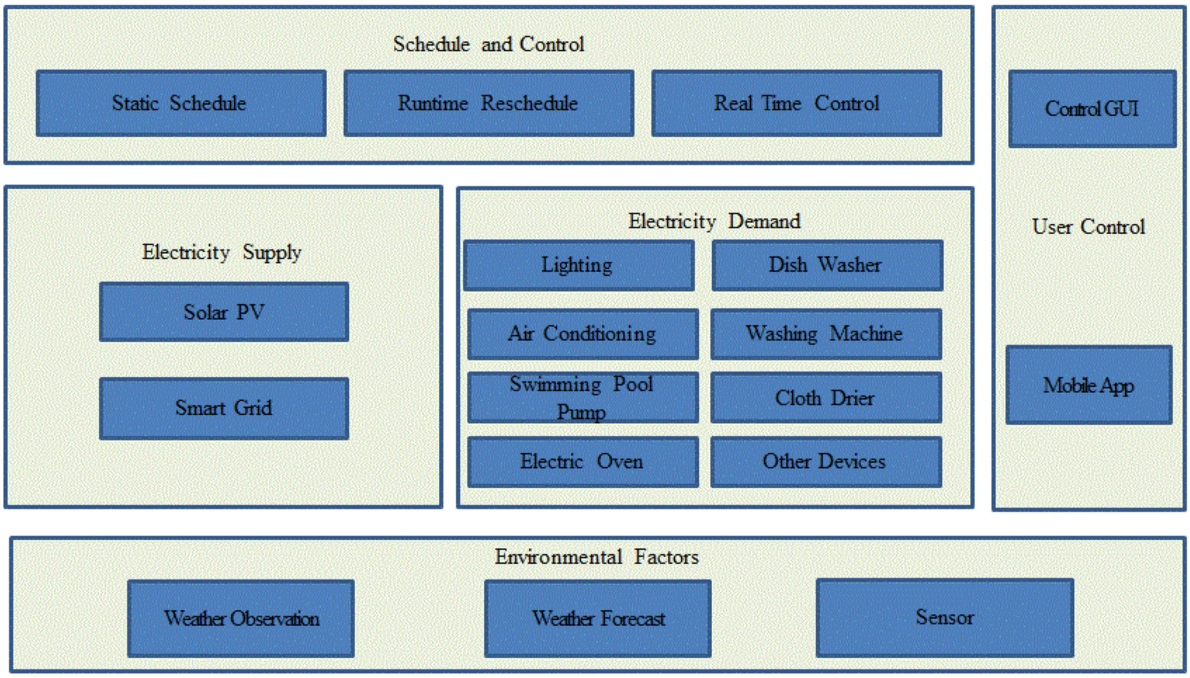

Fig. 2. System Modules of Power Smart Home System

The package "**Environmental Factors**" has classes "*Weather Observation*", "*Weather Forecast*", and "*Sensor*". The "*Weather Observation*" collects and saves local area's weather observation data of the residential home from online broadcast services of weather observation. "*Weather Forecast*" collects and saves local area's forecast weather data of the residential home from online weather forecast services. The "*Sensor*" class collects and saves temperature sensor data according. It has one method to collect data in a fixed time interval and another method to collect data at real time.

The package “**Power Supply**” has classes “*Solar PV*” and “*Smart Grid*”. The “*Solar PV*” has a method to fetch power generation data from ZigBee Panel Meter, a method to format and save data in the “*Solar_PV_Tab*” of “PowerDB” database, and a method to control the solar PV. The “*Smart Grid*” has a method to fetch smart grid data from ZigBee Panel Meter, a method to format and save data in the “*Smart_Grid_Tab*” of “PowerDB” database.

The package “**Power Demand**” has classes “*Lighting*”, “*Air Conditioning*”, “*Swimming Pool Pump*”, “*Electric Oven*”, “*Dish Washer*”, “*Washing Machine*”, “*Cloth Drier*”, and “*Other Devices*”. Each class in this package has a method to fetch power consumption data from ZigBee Panel Meter, a method to format and save data in the corresponding table of “PowerDB” database, a method to monitor the status of the appliance, and a method to set the running mode and control the appliance.

The package “**User Control**” has classes “*Control GUI*” and “*Mobile App*”. The “*Control GUI*” has a graphic user interface for the home occupants to monitor and control the smart home system. The “*Mobile App*” provides the remote access of the smart home system. The “*Mobile App*” will run on smart phones as an application. Home occupants can remotely monitor and control electricity facilities including household appliances, solar PV, smart grid, and home sensors.

The package “**Schedule and Control**” has classes “*Static Schedule*”, “*Runtime Reschedule*”, “*Real Time Control*”. The “*Static Schedule*” performs the task to make a static schedule for electricity consumption of household appliances in the context of local power resources and smart grid according to the weather forecast and occupants’ predictable activities. The “*Runtime Reschedule*” looks after the rescheduling for electricity consumption of household appliances as response of real time status of power consumption. More details of “*Static Schedule*” and “*Runtime Reschedule*” will be provided in the following two sections. The “*Real Time Control*” manages real time control requirements by calling control methods defined in classes for solar PV, household appliances, and sensors.

4 Static Scheduling and Runtime Rescheduling

This section provides the description of day-ahead static scheduling and runtime rescheduling of electricity consumption of household appliances in the context of weather forecast and occupants' activity plan.

4.1 Static Scheduling

The proposed day-ahead scheduling scheme in our previous work [7] is employed to build up the “Static Schedule” class. In the proposed static scheduling scheme, the energy models and profiles of smart grid, local power resources, and household appliances at residential homes are defined in the context of weather forecast and occupants’ activity plan. It is assumed that the smart grid has a variable electricity tariff and electricity power cannot be sold back to the smart grid when the electricity voltage of the smart grid is equal to or higher than a threshold value. The schedule of electricity consumption and local generation at a residential home has been identified as an optimization problem for minimizing the total cost of electricity power while satisfying power requirements at a residential home. A practical first-principle-based solution has been developed for making the static schedule to achieve the approximate minimum total electricity cost. The static scheduling scheme has taken into account of the dynamic relationships among local power generation, power supply of the smart grid, and consumption demand. In the “Static Schedule” class, the profiles of smart grid, local power resources, and household appliances are built up based on data stored in “PowerDB”. The profile of smart grid is generated by querying “PowerDB” tables “Smart_Grid_Tab”, “Weather_Observation_Tab”, and “Home Calendar Tab” with local weather forecast data and occupants’ activities plan. The profile of local power resources is generated by querying “PowerDB” tables “Solar_PV_Tab”, and “Weather_Observation_Tab” with local weather forecast data. The electricity consumption profile of each household appliance is generated by querying the corresponding “PowerDB” table for the appliance and “PowerDB” tables “Weather_Observation_Tab”, and “Home_Calendar_Tab” For lack of space, here we only provide the above high level description. The detailed description of static scheduling could be found in [7].

4.2 Runtime Rescheduling

The static schedule is created by optimizing the running of household appliances in one day period to minimize the total cost of electricity power. The “*Static Schedule*” class will take charge of this task. The static schedule is based on the statistical prediction of smart grid, local power generation, and consumption demands of household appliances in the context of predictable weather conditions and occupants' activities plan. In real time, weather conditions and occupants activities could have big differences from what they have been predicted to be. The operation status of the smart grid, local power generation, and household appliances could be far away from what they are in the original static schedule. It is necessary to reschedule the running of flexible household appliances. The runtime rescheduling happens in the following two cases:

- Weather conditions according to updated weather forecast are significantly different from what they are in previous weather forecast when the original schedule is made.
- Before running a household appliance with a flexible starting time, it is found that there is significant difference between the real time status of smart grid, local power generation, and electricity consumption of household appliances and what has been predicted when the original schedule is made.

The "*Runtime Reschedule*" class has one method to perform runtime rescheduling in above first case and another method to perform runtime rescheduling in above second case.

5 Related Work

The challenges, research questions of energy informatics have been discussed in [11]. The development of environmentally sustainable business practices have been highlighted in the perspective of information systems. [12] provides a survey of the common trends for renewable energy systems of wind and solar-PV and energy-storage systems of flywheels, hydrogen, compressed air, supercapacitors, superconducting magnetic, and pumped hydroelectronic. [3] presents the assessment of future costs and technical potential of renewable energy sources including wind, solar-PV, biomass, and liquid fuel from biomass. [13] discusses the surplus-electricity production problem due to fluctuations of sustainable energy resources. The flexibility in electricity management is recommended by either reducing the surplus production or moving electricity demands from high price periods to low price periods.

Smart home [1] has been coined as a concept to incorporate domestic devices that control features of the home by exploiting a broad range of enabling technologies such as smart appliances, sensor networks, smart grid, local renewable energy sources, and data communication technologies. There have been a number of projects being developed for the purpose of proof-of-concept demonstration of the smart home concept. [14] presents an overview of the smart home concept and some challenges that information and communication technology will face in the smart home environment. Related to smart home, domotics, more commonly known as “home automation”, have attracted more attentions in recent years to control entertainment, heating, broadband, lighting and security from one of many types of digital computer control devices, panels and mobile handset [15].

The authors in [16] propose a rule-based framework based on Event-Condition-Action pattern inherited from the field of expert systems for heterogeneous subsystems management in smart home environment. This work focuses on Event-Condition-Action rule mechanism without detailed description of components of a smart home system. [17] explores the relationship between human and automated intelligence and how it is manifest in green buildings. The concept of “occupant intelligence” is emphasized for providing flexible, adaptive task environments, refined control zones and technologies that maximize occupants’ access to adaptive opportunities. [18] reports a simulation system for validating contextual rules in smart homes in the context of a smart home being capable of sensing the home’s occupants and their current requirements and states, and providing optimized services to them. This work is still at its early stage and only high level results are provided.

MavHome is proposed in [19] as an agent-based smart home which allows a home to act as an intelligent agent in an adaptive and automated environment. This research is at a high abstract level without considering specific features of home appliances and/or inhabitants. [20] reports the research on semantic representation of energy-related information in future smart homes. The proposed knowledge base follows the Web Ontology Language standard. This work focuses on the representation of individual home facilities and their energy demand or supply. The dynamic relationships of facilities in smart homes are beyond it major concerns.

The smart grid is a convergence of information technology and communication technology with power system engineering by enabling utilities to make more efficient use of their existing assets through demand response, peak shaving, and service quality control [5]. In a smart grid, micro-grids will be integrated in a manner of plug-and-play through dedicated highways for data collection and power exchange. [21] overviews the approach toward a smart grid with high level description about how to make an electronic power transmission system smart, the advantages of an intelligent processor in each component, substation, and power plant, diagnostic monitoring of transmission equipment, and the electric power system as a complex adaptive system. [4] presents the approach to build smart appliances which can sense the environment. This work provides a terminology that discriminates the real-world situations, the data collected, the abstraction of data, and the application that makes use of the knowledge. [22] employs a user-centric perspective for mapping consumers' perception of the possibilities of demand side management through smart household appliances in smart grid.

On the foundation of existing academic research and industry initiatives on smart grid, smart appliances, smart homes, and renewable energy sources, we work on a smart home system approach focusing on power management at residential homes in the context of smart grid. The power smart home system aims to achieve more efficient use of energy utilities at a resident home by considering the status of smart grid, local power generation, and electricity demands of household appliances in the context of weather conditions and occupants' activities plan.

6 Concluding Remarks

The research interest of energy efficiency at residential homes is rapidly growing further with the advances of emerging technologies of smart grid, sustainable energy sources, smart appliances, electricity smart meters, and accurate monitor and prediction of environmental factors. This paper reports our early stage research on power smart home system in the context of smart grid. The system architecture has been presented with details of communication network, data storage, and system modules. The static scheduling and runtime rescheduling have been described. The proposed power smart home control and management approach has the capability to manage and coordinate household appliances and local power generation with consideration of the status of smart grid, weather forecast and observation data, activities plans and requesting commands of home occupants, real-time data from sensors. This early stage work highlights the research motivations and high level design of the proposed power smart home. The proposed architecture will provide a solid foundation for evolving power smart home system in its implementation in the reality. More details of proposed approach and the cost/benefit analysis will be provided in the future.

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Use Cases & Requirements for Smart Home Environment

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Abstract

The main target of the European standardization group CENELEC TC59X/ WG7 is to define the Smart Home/Smart Grid standard for Home Appliances, based on the scope

> Standardization work to enable domestic appliances to improve functionality through the use of network communication.
>
> Examples of network communication include smart grid, smart home and home network.

The main difference between Single Home Appliances and Smart Appliances in a Smart Home/Smart Grid environment is the dependency on networked systems with different stakeholders like Grid operators and Home and Building Managers realized by lots of different manufacturers.

This means that a Smart Appliance is not anymore a stand-alone device but embedded in a communication system with different other Smart Devices like Smart heating systems, Electric vehicles etc.

In this context interoperability is key to ensure the success of Smart Grid and Smart Home. A customer of a Smart Appliance does not want to be confronted with technology, he needs solutions. Having this in mind, interoperability requires open signals and messages to be understood by Smart Devices (like Smart Appliances) independent from different manufacturer

As this target influences the requirements of the whole chain from the interface of the Grid into the premises, the in-home management and the Smart Devices, TC59X/ WG7 has liaisons with IEC TC57/ WG21 (Definition of the interface Grid – Premises) and CENELEC TC205/ WG18 (In Home Distribution and – Management).

The most significant tasks in these standardization bodies are

> a common architecture (on a logical basis)
>
> and
>
> common use cases.

to set up the basis for interface definitions and common signals & messages to finally enable interoperability.

Within 2013, all these standardization bodies will deliver first drafts of their standards.

The presentation will show an overview about the work on common architecture and use cases, their impacts on Grid and Smart Appliances and the status of interoperability.

Introduction

The transition to a new "electrical era" in which electricity is becoming the preferred energy source for most everyday applications is currently taking place. This is governed by three key factors: demographic change, scarcity of resources, and climate change. In the meantime, two development trends are of particular interest:

- the demand for electricity is continuing to grow
- the energy system is subject to dramatic changes

Until recently, load dictated production, a method which influenced how interconnected power systems were designed. Power generation was centralized, controllable, and above all, reliable. The load was statistically predictable, and energy flow was unidirectional, that is from producer to consumer.

These aspects of power generation are changing. Firstly, the rising percentage of fluctuating production within the energy mix brought about by renewable reduces the level of power generation control available. Secondly, the energy flow is no longer unidirectional sent from producer to consumer; now the consumer is slowly turning into a "prosumer," a term which denotes a person who produces and consumes energy. More and more consumers are installing their own renewable energy products to increase energy efficiency. These prosumers are cogenerating heat and power with their own solar panels or microCHPs, for example. This trend is set to continue, as government bodies continue to provide incentives to domestic users to become "prosumers" as part of their increased energy efficiency policies.

Ultimately, the way of the future will most probably have to be that, up to a certain extent, the load follows the energy availability.

Figure 1 lists examples of Smart Devices and their capabilities.

The change, raised in this extract of a *Demand Response White Paper* of Siemens AG [7] does not only require technological solutions but also an economic framework to e.g. ensure customer benefits like flexible tariffs. However, as our standardization efforts are focusing on technological solutions, economical frameworks are not part of this report.

Furthermore, Smart Grid / Energy Management functionalities are only one part of Smart Home & Building capabilities. However, in terms of communication requirements, Smart Grid solutions can be used as blue print for interoperable communication methods. All other sectors like AAL, convenience, security etc. can be defined based on this blue print method and can be added on top of Smart Grid related signals & messages.

Table: Demand response communication infrastructure				
Device type	Influenceable		Storage/ buffer	Comment
	Generation	Consumption		
Wind turbine	■			Only reduction of actual generation
Photovoltaic generation	■			Only reduction of actual generation
Backup generators	■			
Solar water radiators		■	B	Additional electrical heating in boiler required
Combined heat and power	■	■	B	Additional electrical heating in boiler required
Heat pump with boiler		■	B	
Electric radiators		■		
Central air-conditioning		■	B	
Decentral air-conditioning		■		
Drives for ventilation		■		
Drives for water pumps		■	B	Requires water tanks on top of buildings
Other drives		■		Elevators, escalators, etc.
Household appliances		■		Washing machines, tumble dryers, dishwashers, etc.
Industrial processes		■	S/B	Storage/buffer capability depends on process type
Batteries and supercaps	■	■	S	
E-cars (home charging)	■	■	S/B	Feedback is currently only future option
E-cars (public charging)		■		

Figure 1: Examples of demand response devices & capabilities (see *Demand Response White Paper* of Siemens AG [7])

Scope of this report

The success of the Smart Grid and Smart Home approach is very much related to interoperability, which means that all Smart Devices in a Smart Grid, Home & Building environment have a common understanding of signals & messages in a defined interoperability area (in a broader perspective, it doesn't matter if it as an energy related signal, a home management signal or an information signal).

Examples of signals & messages are:

- the expected energy consumption of the upcoming cycle of my appliance is 2kW
- please start in 2h
- my door status is open
- next tariff structure is “20ct from 8:30h – 10:00h, 25ct from 10:00h – 12:00h”

We use the term signals & messages instead of commands, as customer have the right to overrule decisions coming from e.g. the grid. Signals & messages represent a suggestion instead of a direct advice. Specific contracts between customer and supplier however may lead a signal to behave like a command.

This report describes the process, steps and involved parties to develop common signals & messages mainly for Smart Grid / Energy related purposes

Involved standardization bodies

IEC TC57/ WG21 (Interface into the premises), **CLC TC205/ WG18** (Inhome Distribution) and **CLC TC59X/ WG7 / IEC TC59/ WG15** (Smart Appliances) develop **individual standards** defining interfaces and related signals & messages within their area of responsibility.

Fig. shows a rough overview of main standardization bodies *(map has no request to be complete)*

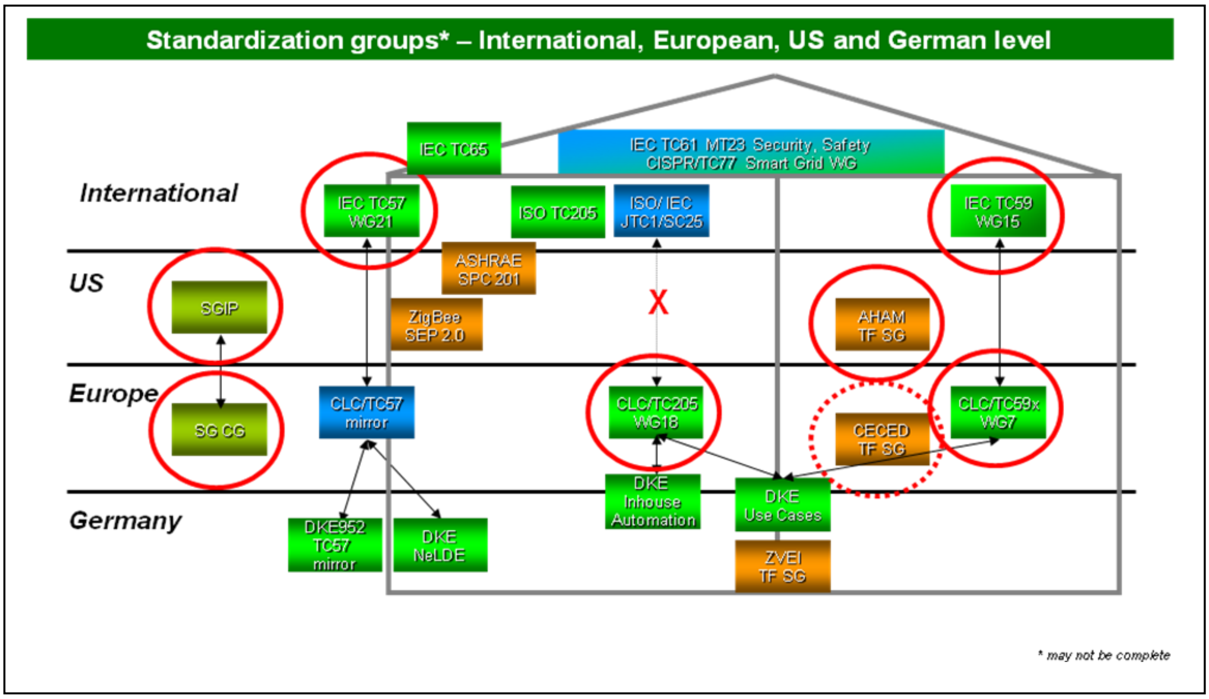

Figure 2: Standardization bodies and association involved in Smart Grid & Smart Home activities

To ensure a proper and interoperable behavior of smart devices within smart premises, the whole chain from the interface into the premises until the Smart Device is affected and impacts. Therefore a Joint Working Group Use Cases & Requirements has been formed under the roof of IEC TC57/ WG21 by members of all mentioned standardization bodies to develop a Technical Report as basis for the individual standards. This work is done collaboratively as it is tremendously important to prevent or at least diminish different interpretations. It also uses already existing results from other working groups like Smart Grid Coordination Group [5] or IEC TC8 but fills gaps left.

This work includes to

- describe a logical architecture
- describe a set of user stories that describe a number of situations related to energy flexibility and demand side management. The set of user stories does not have the ambition to list all home energy management possibilities, but is meant as a set of examples that are used as input in use cases and to check that the set of use cases is complete;
- describe a set of use cases based on the user stories and architecture. The use cases describe scenario's in which the communication between elements of the architecture is identified;
- further detail the communication identified in the use cases is by describing the signals and data models.

This procedure can also be used as a blue print for upcoming Smart Home solutions like Remote Control, Remote Monitoring, Ambient Assistant Living and so forth.

Architectural requirements

The architecture, shown in this report, is focusing on in-home architectural requirements and is a functional reference diagram, described in the Smart Grid Coordination Group – Working Group Sustainable Processes Report [5].

In this logical architecture the Smart Grid Connection Point represents the interface from the Grid into the premises. The CEM (Customer Energy Manager) provides the flexibility of connected smart devices, through the energy management gateway, while the smart metering and the simple external consumer display provide a number of functionalities which are described in more detail in work of the Smart Meters Coordination Group [6]. The energy management gateway communicates with the metering channel and the smart metering through the Smart Metering Gateway. The gateways in this architecture split different networks (Wide Area Network, Neighborhood Area Network and Local Area Network) and may be, as further described below, integrated with other functional entities.

The Customer Energy Manager (CEM) is the central managing function. It decides and manages based on information coming from the grid and/or from the Smart Devices. The term "Energy" within CEM reflects the demand of SG CG to focus on Energy. In a typical home or building environment this manager will likely manage all kinds of future management scenarios and will be the basis for AAL (Ambient Assistant Living) and other future user scenarios.

The architecture does not force a CEM to manage more than one device. Therefore it can be part of a single Smart Device (e.g. included in a Smart Appliance) and manage only this device. As this is a redundant functionality (with probably proprietary interfaces, if included in a specific device), it is not specifically examined in this report

The external actors A and B, identified in this functional architecture represent (systems of) market roles that communicate through the Smart Grid Connection Point. Examples of these roles are a Grid operator, meter data collector, meter operator, aggregator, supplier, flexibility operator, etc.

The actual role of actor A or B depends on the local market organization in a member state and competition. In the scope of this report, actor A is defined as the external actor communicating with the energy management gateway while actor B is defined as the external actor communicating with the smart metering gateway.

For sake of simplicity, the use cases in this report do not represent the energy management gateway and the smart metering gateway - when developing the use cases we assumed that the gateways do not provide functionalities contributing towards the goals of the use cases. These do however provide functionality in terms of routing information, translation of protocols, device management, security and service capabilities

Within this Home Area Network architecture, 3 main different interfaces are necessary to support Interoperability between:

1) Smart Grid Connection Point & Customer Energy Manager via Energy Management Gateway
2) Smart Grid Connection Point or Smart Meter & Customer Energy Manager via Smart Metering Gateway and Energy Manager Gateway
3) Customer Energy Manager and a smart device.

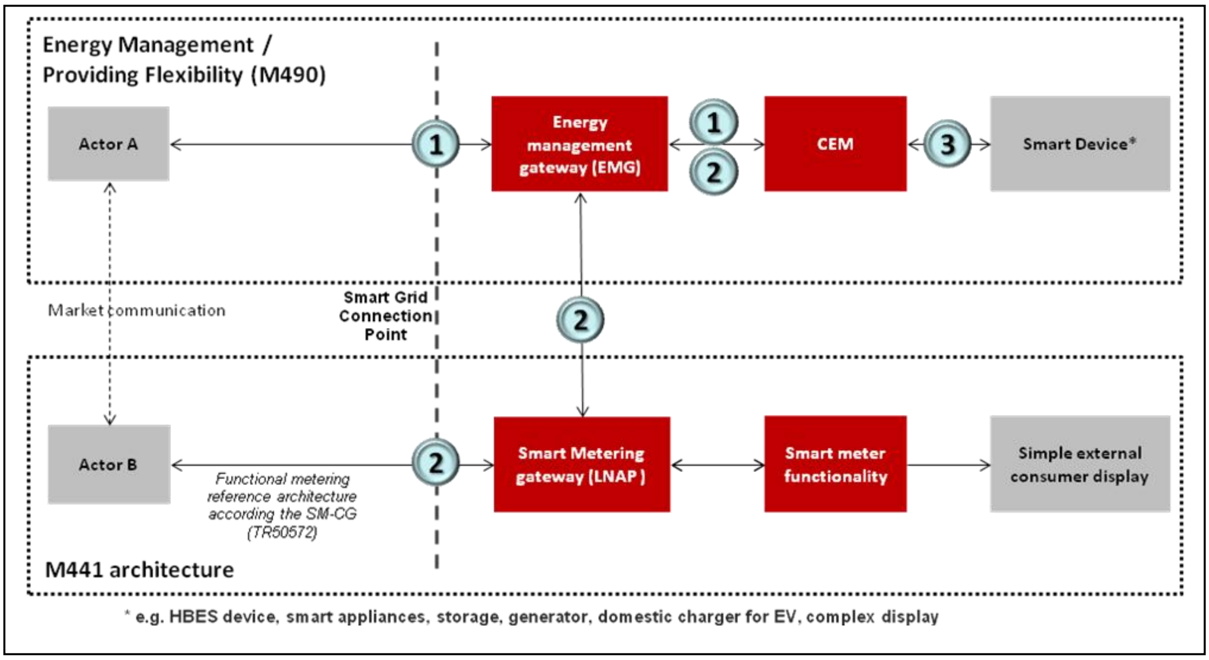

Figure 3: Energy Management Architecture according to EU Mandate M490, Smart Grid Coordin. Group (Smart Devices can be in a range of very simple up to very complex devices)

The main target is to derive signals necessary to ensure interoperability between Smart Grid, CEM and Smart Devices.

These signals are defined on a neutral basis (technology neutral interfaces). Therefore, the mappings onto specific transmission technologies are the responsibility of the equivalent (standardization) bodies like KNX, ZigBee, BACnet, etc.

Figure 4 and 5 describe the neutral interfaces, the connection to domain specific technologies and different kind of Smart Devices

The architecture does neither reflect the intelligence of devices nor give any advice how and where to split the intelligence between CEM and Smart Device. (e.g. simple switch vs Smart Aplliance). It ‘s only requested to define specific signals like

- Switch on (more likely for simple devices)
- Start in 2h.(more likely for intelligent Smart Appliances)
- Switch off (could be valid for all devices)

Details will be part of the specific standard like the Smart Appliance standard (successor of CENELEC EN50523)

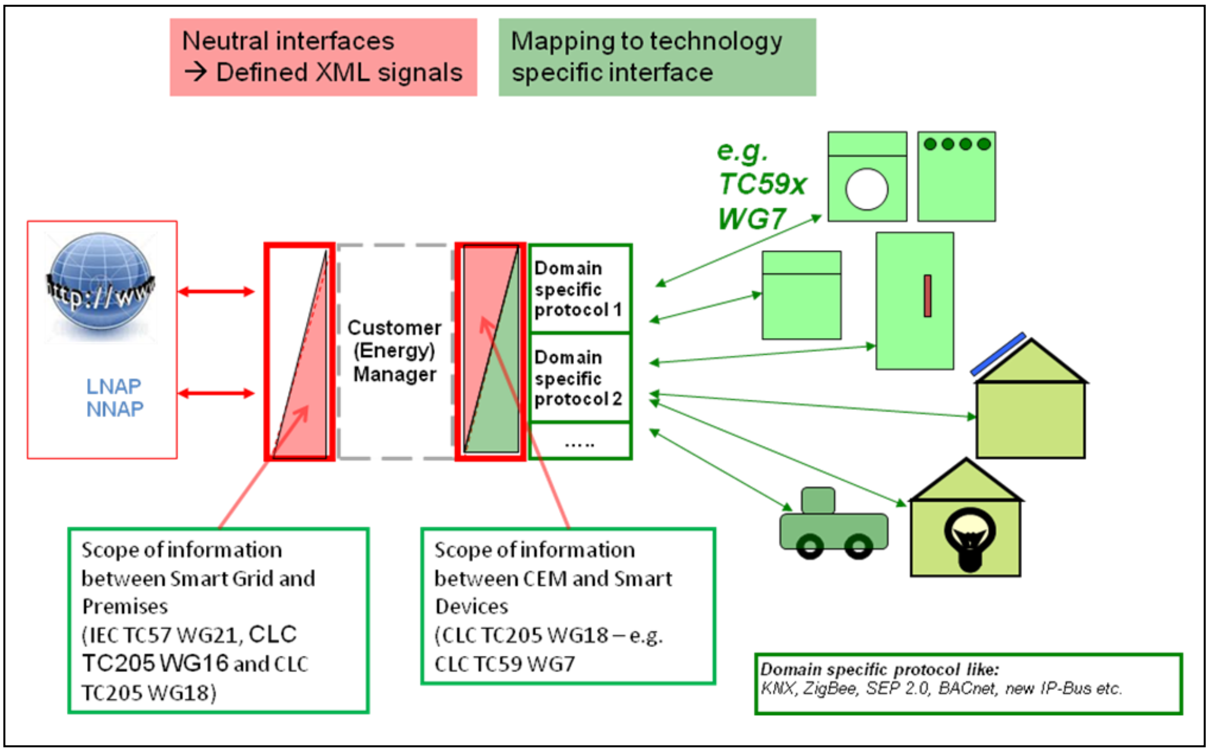

Figure 4: Neutral interface with neutral signals to ensure technology independent interoperability

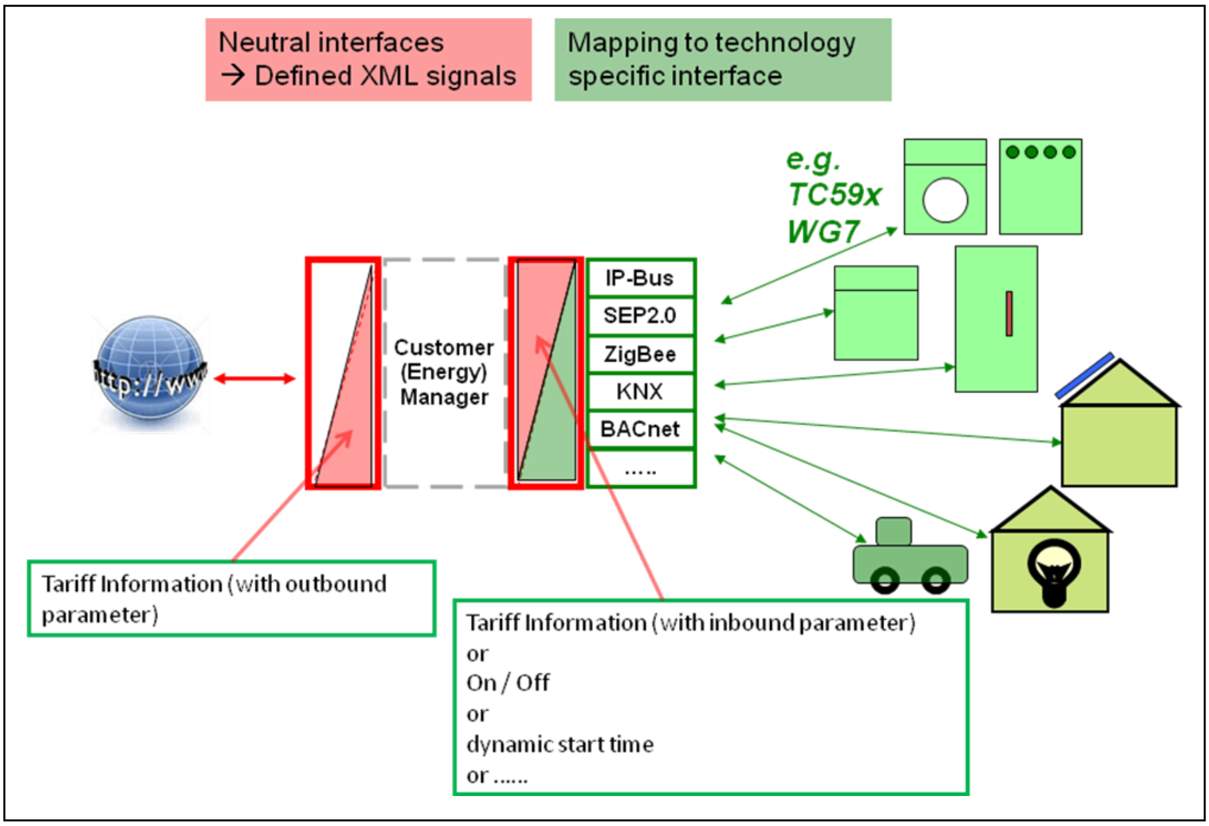

Figure 5: Mapping of signals according to intelligence of Smart Devices

User Stories & Use Cases

Why user stories & use cases?

Standardization does not standardize use cases. The user may use different ways to get to a target or the manufacturer may implement different solutions, means different interpretations of use cases. However the definition of signals and information flows between then different stake holders are essential to ensure interoperability.

Use cases help to collect requirements for necessary signals and messages by describing possible scenarios.

Figure 6 describes the process to define signals and structures.

As already mentioned, only signals & XML/JSon structures will be standardized. Then rest of the process is necessary to achieve the right requirements to ensure interoperability.

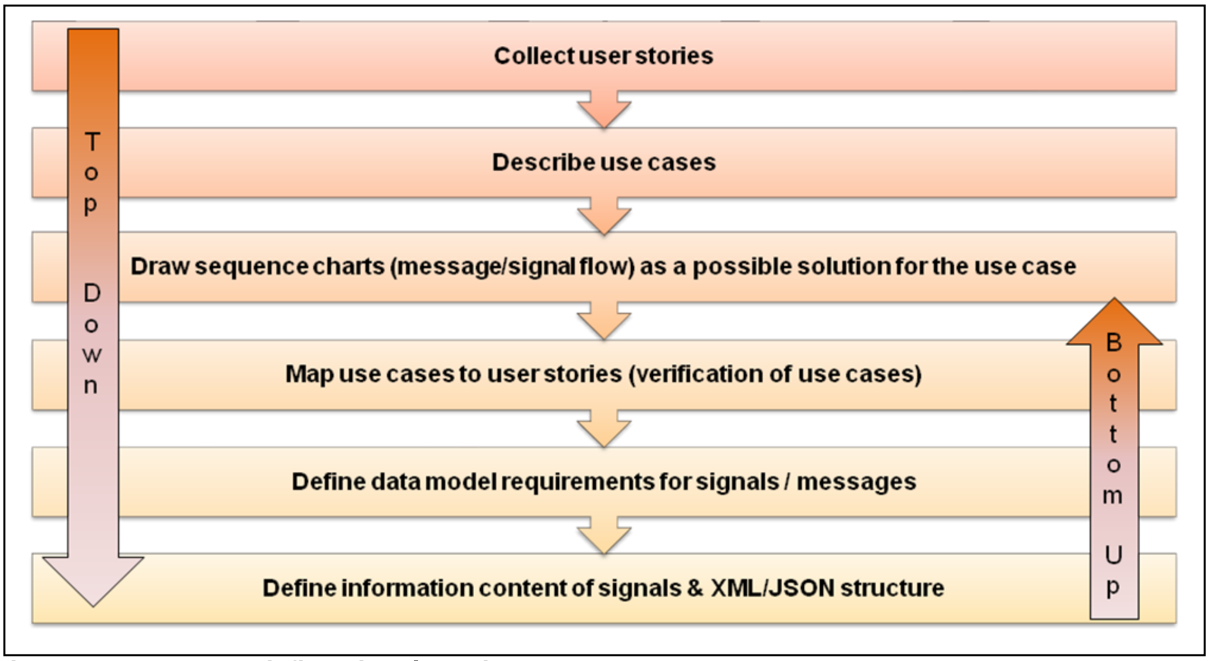

Figure 6: Process to define signals and messages

Relationship between User Stories and Use Cases

User stories are produced from the consumer perspective and describe typical scenarios that a consumer may experience. The list of user stories is not exhaustive. User stories are mapped to more detailed use cases, such that one user story may be realized using one or more use cases. These use cases list a set of data items and signals required for their operation.

Collection of User Stories

The following slide present headlines of typical user stories

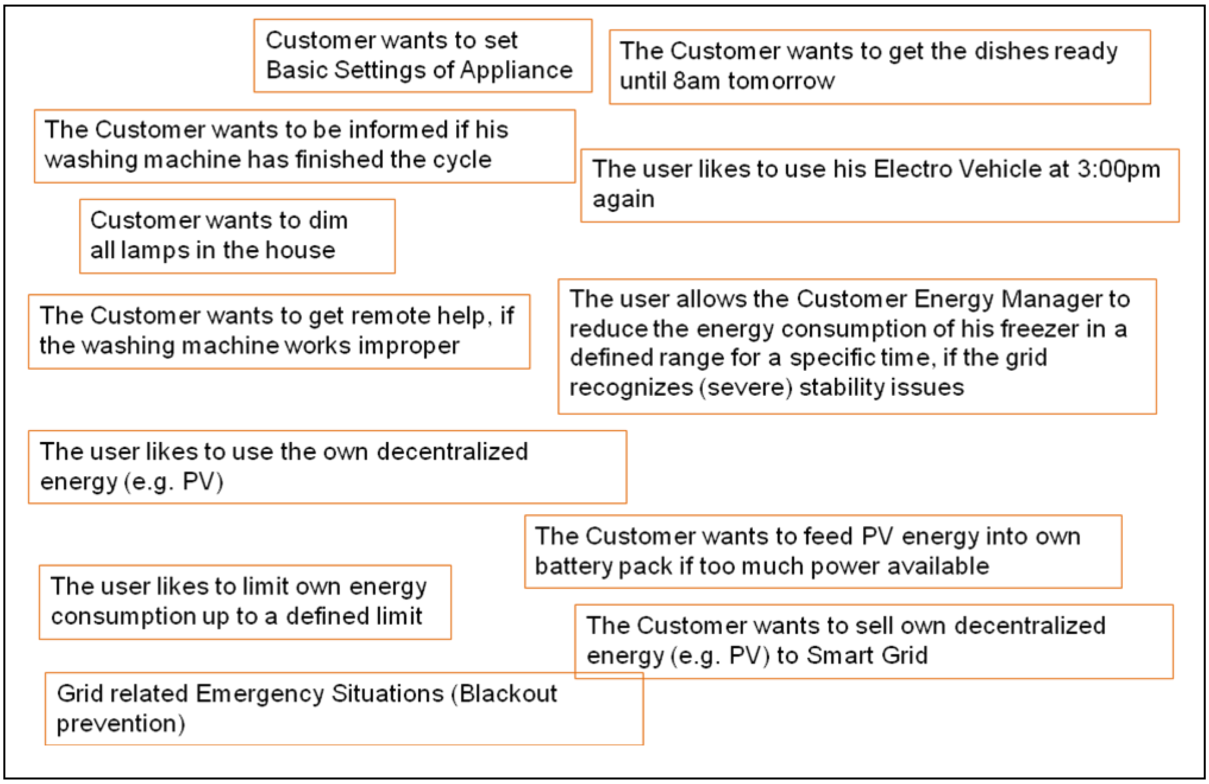

Figure 7: Collection of user stories

Example of a user story: The user wants to get the laundry done by 8:00pm

- The user prepares the washing machine
    - Fills clothes
    - Selects washing program
    - Pre-selects the end time (e.g. 8:00pm)
    - May pre selects the incentive program (e.g. cheapest tariff, greenest power etc.)
    - Starts washing program

- The washing machine now informs the CEM about
    - The start of the new program
    - The pre-selected end time
    - The pre-selected incentive program (if not already stored)
    - The expected power consumption profile with duration and (e.g. time related specific) energy consumption

- The CEM calculates the operation plan and takes into account
    - The pre-selected end time
    - The pre-selected incentive program (if not already stored)
    - The expected power consumption profile with duration and (e.g. time related specific) energy consumption
    - Tariff information

Expected energy consumption other Smart Devices
Expected local energy generation
Amount of locally stored energy

The CEM sends the calculated start time to the Smart Device (washing machine)

The Smart Device starts the cycle based on the calculated start time

This user story describes the story of getting the laundry ready on a flexible energy demand basis. For the customer other stories could also have a side effect on this story like:

- Customer agrees upon a specific contract with his supplier to get financial benefits due to energy flexibility
- A Smart meter needs to measure the appropriate energy consumption and accounting
- And so forth…

For standardization, all stories which may lead to a signal & message on the outer or inner interface are relevant. It is important for the customer to also get a financial benefit but it doesn't influence any part of the technical standard. These stories are not treated here.

Use Cases

The use cases are based on the above described user stories and the architecture defined earlier in this report. Note that the use cases only describe communication between Actor A/B, the CEM, the smart meter and the smart devices. For sake of simplicity, these use cases do not represent the energy management gateway and the smart metering gateway - when developing the use cases, we assumed that the gateways do not provide functionalities contributing towards the goals of the use cases.

Use cases describe a specific step to achieve the targets of my user story.

Figure 8 describes such a use case where the Smart Device informs the CEM about a flexible start request and gets back a starting time.

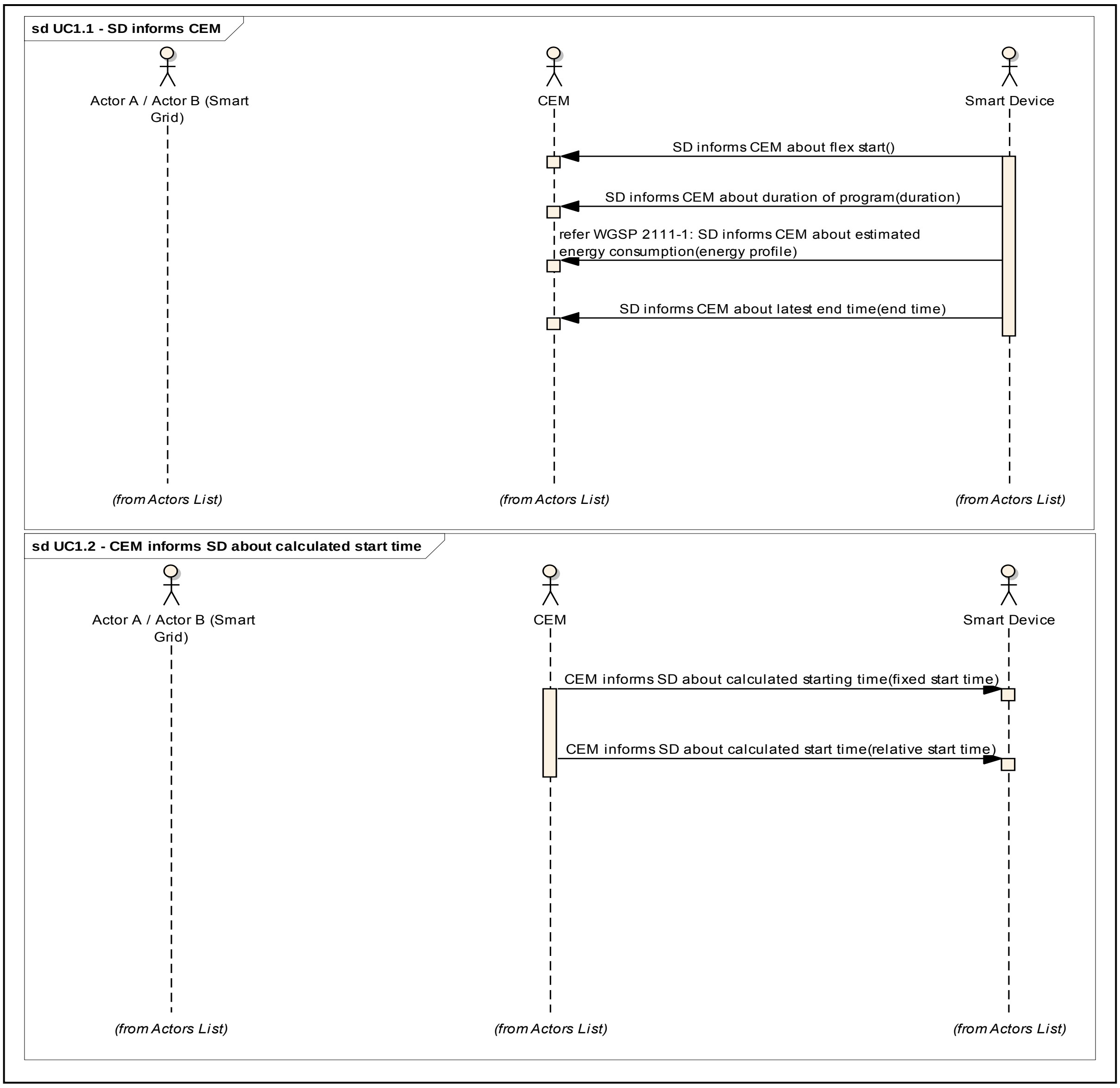

Figure 8: use case examples: Smart Device informs CEM about a flexible start

Use Case mapping (User Stories – Use Cases)

The main intention of a standard should be simplicity. The re-use of use cases requested by different user stories is one of the biggest targets.

As already stated, Figure 8 describes such a use case where the Smart Device informs the CEM about a flexible start request and gets back a starting time. This use case can be used with a washing machine as well as with the charging process of an electric vehicle.

Figure 9 shows a verification table that all user stories are mapped with existing use cases.

User Story	Generic use c							
	UC 1.1 + UC 2.1 Smart device informs CEM	UC 1.2 + UC 2.2 Smart device sends instructions to smart device	WGSP 2111 sc.1 Consumption information of individual devices	WGSP 2111 sc.2 Total household consumption	WGSP 2112 Price & environmental information	WGSP 2113 sc.1 Warning signal from smart device	WGSP 2113 sc.2 Warning signal from CEM	WGSP 2114 Retrieve smart device status
The user likes to get the laundry ready until 8:00pm								
The user likes to likes to use his Electro Vehicle at 8:00am again								
The grid recognizes stability issues				GAP		GAP	GAP	
The user wants to limit his consumption to his own local production (e.g. PV)						GAP	GAP	
CEM manages Simple Devices								
The Customer wants to sell his flexibility to the grid								

Figure 9: mapping user stories onto use cases *(black = is used, grey = indirectly used, white = not used for this user story)*

Signals mapping (Signals - Use Cases)

Signals are derived from the use cases and need to be verified with use cases as well

Signals / Messages	Generic use c								
	UC 1.1 + UC 2.1 Smart device informs CEM	UC 1.2 + UC 2.2 Smart device sends instructions to smart device	WGSP 0200 VVO	WGSP 2111 sc.1 Consumption information of individual devices	WGSP 2111 sc.2 Total household consumption	WGSP 2112 Price & environmental information	WGSP 2113 sc.1 Warning signal from smart device	WGSP 2113 sc.2 Warning signal from CEM	WGSP 2114 Retrieve smart device status
On / OFF									grey
DIM									grey
HVAC (Temperature)									grey
Incentives (Tariff Inform.)						black			
Metering Data	grey	grey	grey	grey	black				
Sensing									grey
Time Information									
(Text) Messaging							black	black	
Power Scheduling	black	black	black	black	black				black
Supply Condition									
Tariff information from Grid/Meter									
Real-time			black			black			
Schedule/amounts						black			

Figure 10: Mapping of signals & messages onto use cases *(black = is used, grey = indirectly used, white = not used for this user story)*

Signals & messages

At the final end, only signals, conveyed between two peers, will be standardized. Therefore the requirements for these signals need to be defined.

Example: Incentives (Tariff information)

A Smart Grid Market Role (SGMR) wants to send an incentive information (tariff, price + additional information such as CO2/kWh, percentage of green energy etc.) to a household / building / industry.

incentiveReport requirements (aligned with incentiveRequest):
Basic goal: Send incentives to a smart device, a display or a CEM (these might be different data models)

- Must be able to cope with different (mainly existing and near future) tariff structures:
  - Tariffs which only vary over time (e.g. change every 15 minutes)
  - Tariffs which vary over "tiers" (e.g. change with the energy drawn from the grid or even contingent tariffs)
  - Combinations of those structures
- Shall be able to transport monetary values ($s, €s...)
- Shall be able to transport the currency which applies
- Shall be able to transport forecasts of prices as well as currently applying prices (including forecasts for different price tiers and commodities [gas, water, etc.])
- Shall be able to transport incentives for gas, water, heating, ...
- Shall be able to transport multiple incentives for one single commodity (e.g. for energy drawn from the grid vs. energy fed into the grid, but also for feeding in photovoltaic energy vs. feeding in wind energy)
- …….

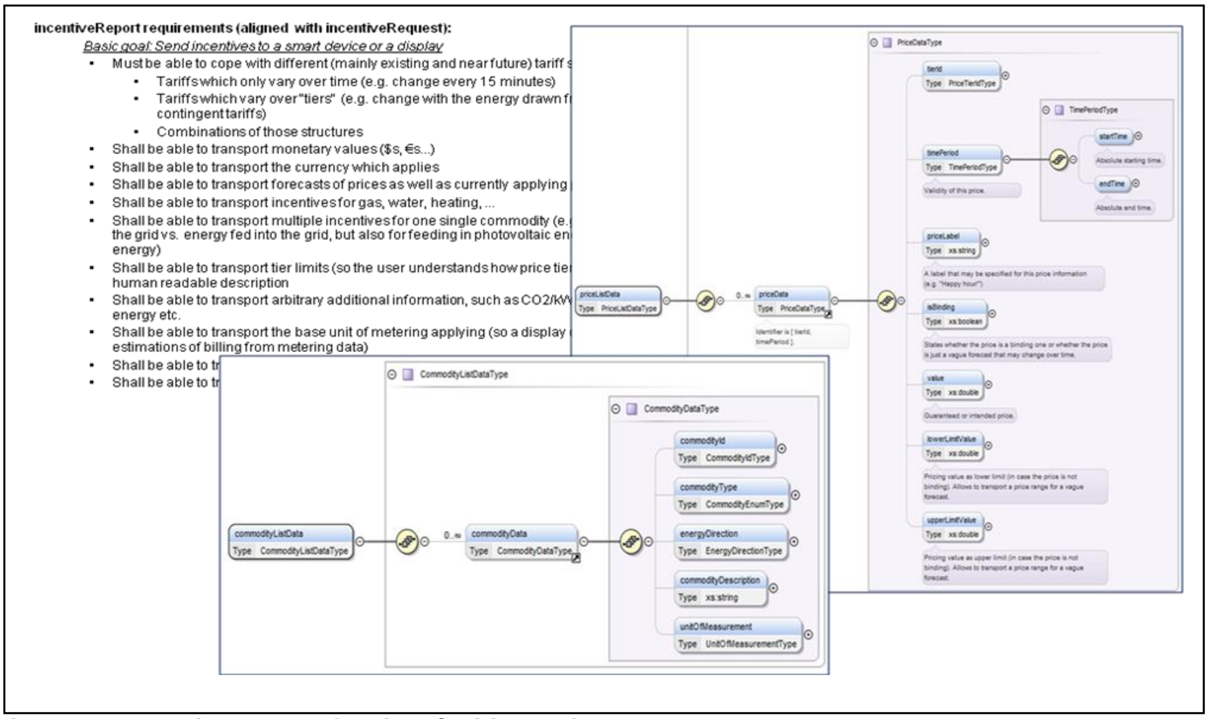

Figure 11: Requirements of a signal with XSD/XML structure

Summary

IEC TC57/ WG21 has just circulated the commenting version of DC_62746-2 (Use Cases & Requirements) document, the focus of this report.

This is the basis for upcoming standards off all mentioned standardization bodies.

All interface specifications of these standards are using the same methodology to achieve the same type of signals & messages and to ensure interoperability.

It is the intention of these standardization bodies to circulate the first drafts within 2013.

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Smart Domestic Solar - Why Solutions for Solar Thermal and Photovoltaic do not integrate into Home Automation?

Gerfried Cebrat

1 Abstract

The term "smart" is widely used for example with "Smart Grids" and "Smart Metering". This paper extends its application to renewable energy systems. Based on the vocational training in the project *Smart-E-Learning*, lead by the University of Applied Sciences FH Joanneum in Kapfenberg and part of an extended elaboration within the project, the paper investigates possibilities for **intelligent control of domestic hot water (DHW) using appliances interfacing with solar thermal controllers** in order to maximise the utilisation of solar energy. Recent advancements of internet enabled micro-controllers using the TCP/IP transfer protocol would allow to (wirelessly) network with the solar controller, washing machines, and hence control the water outtake from the domestic hot water storage tank. Likewise, with island (or remote) power grids and PV **controllers could switch on additional electric appliances** when storage or feed in of electricity is not possible. The said approach was tested at a small domestic solar facility with a solar thermal system. The improvements comprise the connection of a dishwasher to the solar DHW and alternating water supply to a laundry washing machine allowing switching between cold tap water and water from the solar tank as well as heating DHW via surplus energy from a 12 V PV grid. An architecture for implementing networked demand control is presented. Based on the absence of ready to use solutions for small domestic appliances, the paper is also analysing the interest of the stakeholders.

2 State of the Art

Photovoltaic (PV)

Currently, the most advanced integration of house-bound renewable energy facilities with home automation, is connecting PV to heat pumps or air conditioners, having embedded algorithms for cost optimization for the power supply to the appliances, choosing from grid power and own PV-power [1]. Having time variant electricity rates this system concept would require at least another component providing the actual electricity tariffs. The control overhead with such solutions is sold as add-on to the medium to high budget devices. For PV-inverters, Bluetooth communication also is used for switching electrical outlets [2], addressing the same optimization problem, but being not able to negotiate within the course of running processes in the white goods. On the other hand, grid operators are requesting action on the side of the Original Equipment manufacturers (OEMs) of PV-inverters, installing automatic cut out (emergency load shedding), if grid frequencies are surpassing a certain frequency [3]. Several PV-controllers may interact in a modular setting via CAN-Bus [4], which would offer staged feed-in control.

With 12V battery based PV-systems, feeding into the 230V grid could be used to increase the yield. Affordable controllers including switching logic, grid feed in and local 12V storage are not available yet, but the investment will be lower, because only one additional relay between 12V grid and appliance is necessary in the simplest case. With islandic PV-Grids, controllers are available which allow giving preferences to one of two batteries when charging [5]. Exchanging one battery by an electric load allows primitive use of excess power. With battery storage and feed-in inverters, an additional degree of freedom is given and may be exploited. In the absence of a communication bus, existing PV powered irrigation pump control is employing direct wiring to the controller/inverter [6] to switch the pumps according to the PV yield.

Solar thermal

Solar thermal and combinations with PV (PV-T) have lower thermal efficiency at elevated fluid temperatures. Adding low temperature demand helps to rectify this, if operation is planned properly. Secondly, blending hot and cold water - adding entropy- should be avoided, providing water with the right temperature directly to the DHW appliances. Current hot water consuming appliances in households such as washing machines, dishwashers and the like on the one and solar controllers on the other side do not share information and do not allow building upon intelligence, solving those problems.

Climate zones are leading to different types of domestic hot water solar systems. In the non-freezing climates, devices do work without electronic control being buoyancy driven. Those cheap systems are in sharp contrast to Central and Northern Europe, where the investments into domestic solar hot water are higher and thus contributing to a steep decline in new instalments, starting with the year 2008 [7]. Existing European controllers for solar thermal, being capable of implementing the logic needed for interaction with appliances and DHW temperature control, would add a few hundred Euros to those costs, pushing smaller DHW-systems (sized for monovalent operation during summer and located in less sunny climates) further into economic inefficiency.

With solar thermal instalments, the most advanced concepts for DHW and room heating integrate a solar storage into the central heating device, placing small DHW tanks in the storage tank or adding external heat exchangers for DHW [8]. This allows using solar heat at a lower temperature level, because of the final heating option using auxiliary fuels providing extra heat also at elevated temperature. However, in summer with not oversized solar collectors, auxiliary heating systems cannot be shut off because of the DHW demand, requiring low standby losses of the auxiliary heating system. In order to utilize most solar heat, solar storage can provide DHW of the right temperature level. For connecting DHW using appliances - such as washing machines - to solar controllers, only time based switching is used currently. The existing external switching devices [9] do cost approximately 200€, without having the ability to exactly follow the process of the washing machines and without the ability avoiding exergetic losses by providing non premixed warm water with the right temperature. Recently systems that are more complex allow even recuperation of solar heat when cooling brides of tumble-driers. Those systems which approach the target of increasing the solar use in summer very well, are based on bilateral co-operation between a producer of white goods and producer of solar thermal systems and do require four pipes between tumble dryer and solar tank; two for hot water supply and two for condensing cooling [10].

Energy Management in General

So far, at least one OEM for white goods has liberated access for M2M communication, in this case using power line carrier (PLC) communication [11] allowing dynamic load control, but there exist several non-compatible company solutions in parallel [12]. Producers of external controllers may profit from PLC, but also negotiate other communication layers, EN50523 only specifies functional and data architecture.

Concerning predictive control, weather forecasts obtained via the Internet might be integrated. So far, this is mostly used employing the buildings mass for storing away solar excess heat with predicted energy deficits, and the author has written software and tested it in practice successfully [13]. With increasing power demand in households, the potential share of solar thermal on the total energy balance sheet is decreasing and more focus is to be given to demand control and storage of electric energy. The following Figure 1 depicts the options for an energy management, having different topologies, able to manage solar use better. Synthesis of compressed natural gas is a two-step process using electrolysis producing hydrogen [14] and not suited for a domestic scale. Bundled demand control might have enough potential in terms of switched power not requiring investments into energy storage equipment wearing out and generating additional costs:

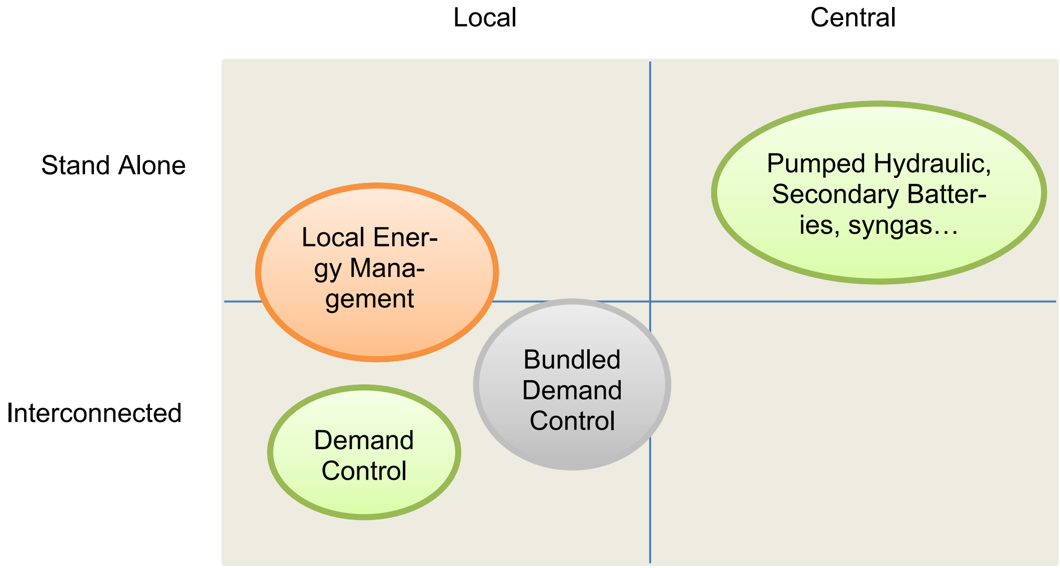

Figure 1 Energy Management approaches

3 Characterisation of Appliances

With domestic appliances, namely white goods, the temperature level for DHW demand widely varies. Lower temperatures allow increasing solar use. In order to save on exergy it is also possible to switch from electric heating to hot water supply. Figure 2 allows to judge whether this option is feasible for the appliances.

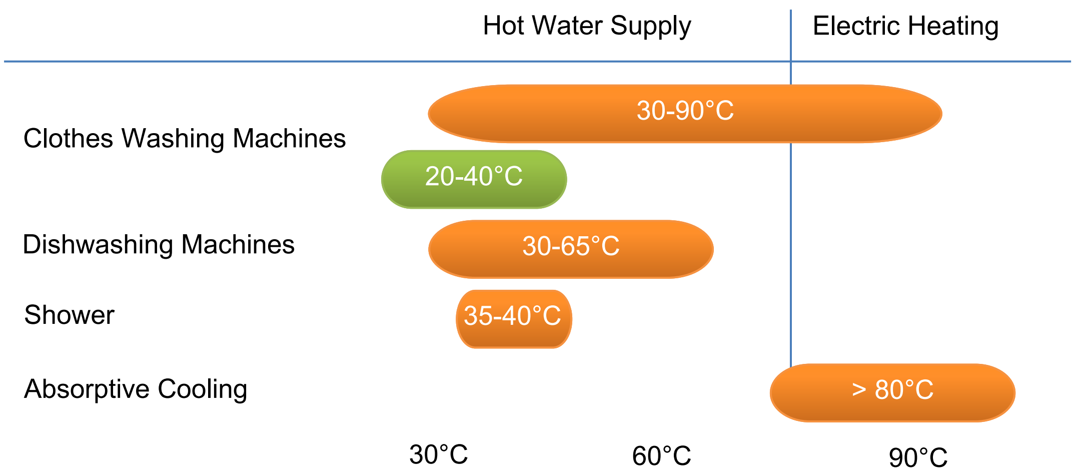

Figure 2 Suitable heating sources for household appliances

With clothes washing machines, users may decide to lower temperature and use low temperature detergents, so electric heating is no longer necessary. In principle, use of electricity can be restricted to providing mechanical power for all those applications, if there is no excess in PV-power to be consumed. However, since feed in tariffs are cut, electrical heating returns on the agenda. Compared to solar thermal, electrical heating is much easier to erect, requiring no piping. Regarding efficiency, solar thermal systems starting with a yield of only 30% of the total insolation [15] are not much better than newest PV-panels reaching an efficiency of 20%, achieving 25% [16] on a cell level and targeting 34% for concentrating PV-systems [17].

Therefore, there is some need for improvement for solar thermal, keeping this pace of PV, increasing the utilization rate of the insolation when operating solar thermal systems. The measured test run of a test installation with connected dishwasher and clothes washing machine has shown that providing low temperature water to the appliances operating the DHW-tanks without electric heating may significantly reduce the gap between the solar yield and the energy used by DHW. Figure 3 shows the difference for the cumulated energy balance of the balcony based solar thermal test system for two years.

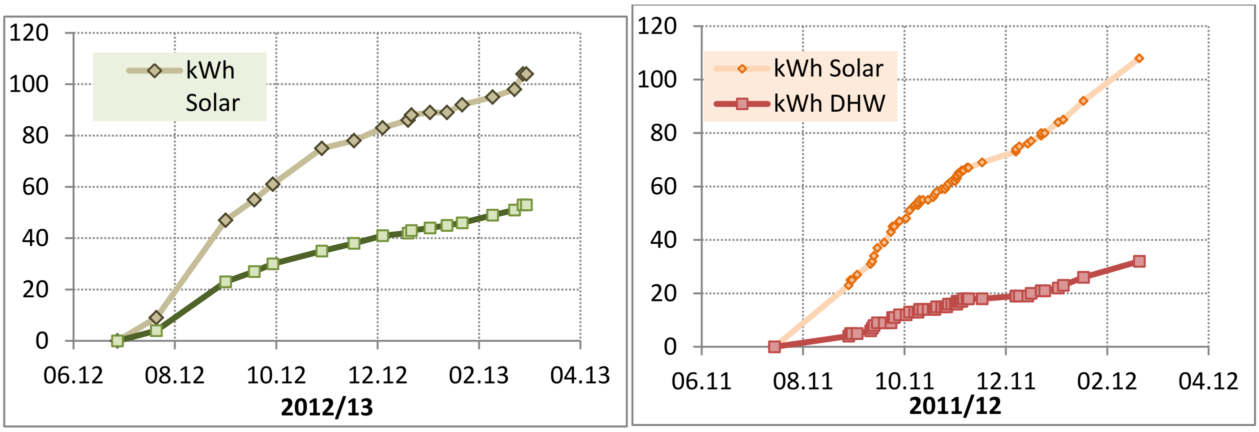

Figure 3 Improvement of the DHW-utilization of the solar yield from 2011/12 to 2012/13, results from the test of a small balcony collector

In autumn 2012 and winter 2012/13 DHW was used for the washing machine independently on the water temperature, the DHW tank was discharged according to the needs disregarding of its temperature. Whilst increasing the efficiency of the solar collector a legionella problem might occur in this setting. It also has to be acknowledged that the total solar use was probably increased only half as much due to the location of the water tank in the kitchen, contributing to room heating during the heating period.

4 Proposition for a networked approach between appliance and solar controllers

In the following, an approach for networking appliances and solar controllers is depicted, following the aims developed in the previous chapters.

Photovoltaic

By exchanging information between appliances and solar controllers, the economy of grid-connected systems may be improved, especially if utilities are practicing PV-cut-outs in times of over-supply or reduce tariffs in those periods. Home automation might support this by controlling the domestic appliances. Domestic systems having long time constants, like cooling or heating, are best suited to compete with feed-in for the **best-cost approach**, because they may absorb larger amounts of energy. In addition, the solar usage factor for 12 V islandic PV grids may be increased by utilising surplus power but feeding into the 230 V home grids is easier and sufficient for small PV-systems.

Solar Thermal

Applying a good hydraulic scheme, the share of solar thermal may be increased significantly. New DHW appliances as dishwashers and clothes washing machines can provide sporadic DHW drain only. Solar cooling would be a more steady demand, contributing more in summer when the solar yield is high. Figure 4 shows a scheme avoiding legionella problems using fresh water heating, introducing new appliances consuming energy, but having bivalent approaches.

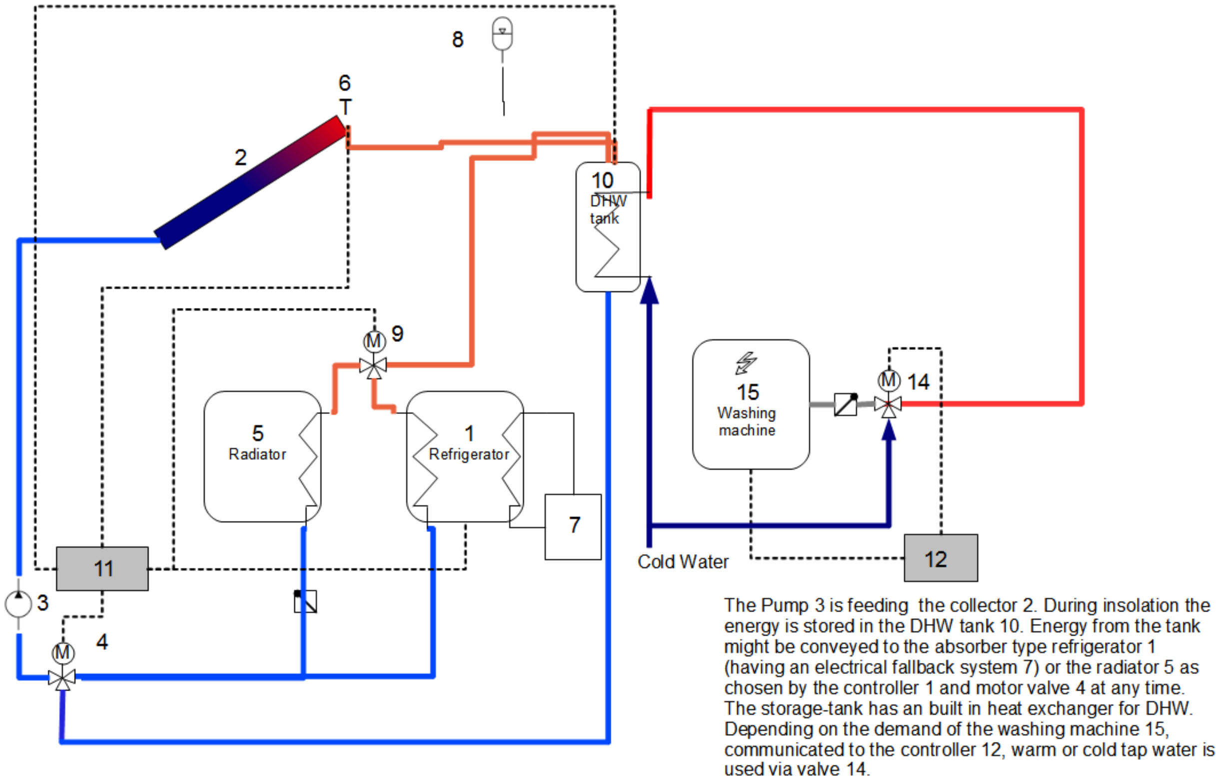

Figure 4 Hydraulic scheme featuring new heat sinks, using storage-tank

Apart from using the solar collector only as heat source, it is also possible using it as a heat sink. Power consumption for refrigeration units and for air conditioning (A/C) is reduced, if the refrigerator and/or the house are pre-cooled overnight. For the refrigerator even cold cloudy days may be used to dissipate heat. This kind of solar cooling does make use of the heat dissipation by the collector at night. With medium temperature solar collectors also, Solar Cooling using absorptive processes is a way making better use of the solar yield in summer but requires an elevated temperature above 80°C. Food and drink processors [18] are applications in focus, but load curves for A/C are more in-line with the solar insolation.

In Figure 4 the DHW temperature may be controlled via the mass flow, but this solution will extract energy also from the hotter part of the storage tank through the heat exchanger, thus decreasing exergetic efficiency. Targeting this weak point Pink Gmbh of Austria has introduced a hot water storage tank, allowing seamless variation of the input or output level and thus temperature [19], applicable especially for larger tanks.

Hybrid Schemes

It is also possible to substitute solar heat by solar excess power, which might not be used otherwise or fed in for a reasonable price. Because of the high exergy of electricity, the upper part of a solar DHW tank or storage may be heated or even the water flow directly. Electric heating elements, either in water tanks or in domestic appliances, are cheap and flexible to control via the applied voltage, so this path might be less costly than applying changes to the hydraulic schemes supplying heat to the appliances. Hybrid schemes target an overarching control of DHW appliances and their heating elements on the one and solar controllers on the other hand.

5 Implementation proposal for a networked energy management

Intelligent overarching control for DHW and electric power is seen only with a few integrated sectorial solutions. What is hindering the development of a domestic energy management, including both domestic hot water and electric power partly fed by PV? Here are some hypotheses:

1. Interconnection does not need much hardware effort, but standardization not only on the data and functional level but also an industrial standard concerning the physical communication layer is necessary to lower cost,
2. Control of hydraulic systems is much more expensive compared to control of electric appliances, especially if this to be added individually and not part of the appliances themselves which are bought independently or pre-existing,
3. OEMs are very cautious giving away control over the appliance performance to external controllers because of customer retention policy linked to the washing performance for example.

Ensuring process quality, a negotiation protocol is necessary gaining acceptance from OEMs. The following figures show the data and control rationale, and also the proposed system architecture. It promotes the best effort principle to all connected appliances. This way, concerns about washing quality is no hurdle to the roll out. It is expected that connectivity of all white goods is improving with time. Concerning the substitution of electricity by solar domestic hot water, the hurdles are significant, because of the need for tank control and blending valves for the water supply of the washing machines. It is therefore of utmost importance to place the solar tank near the washing machines, if blending is to be done in the washing machines themselves. In multi-storey buildings, it is possible to use DHW fresh water stations, controlling them according to the demand. However, this way the exergy consumption may be controlled only with switched or actuated tank outlet, because otherwise the tank supplies only one kind of hot medium. With larger tanks, it is possible to switch the effluent outlet appropriately.

Synthetizing the requirements a networked intelligent approach is necessary. Figure 5 shows the data needed to perform strategic energy management and the processing solar controllers in the system.

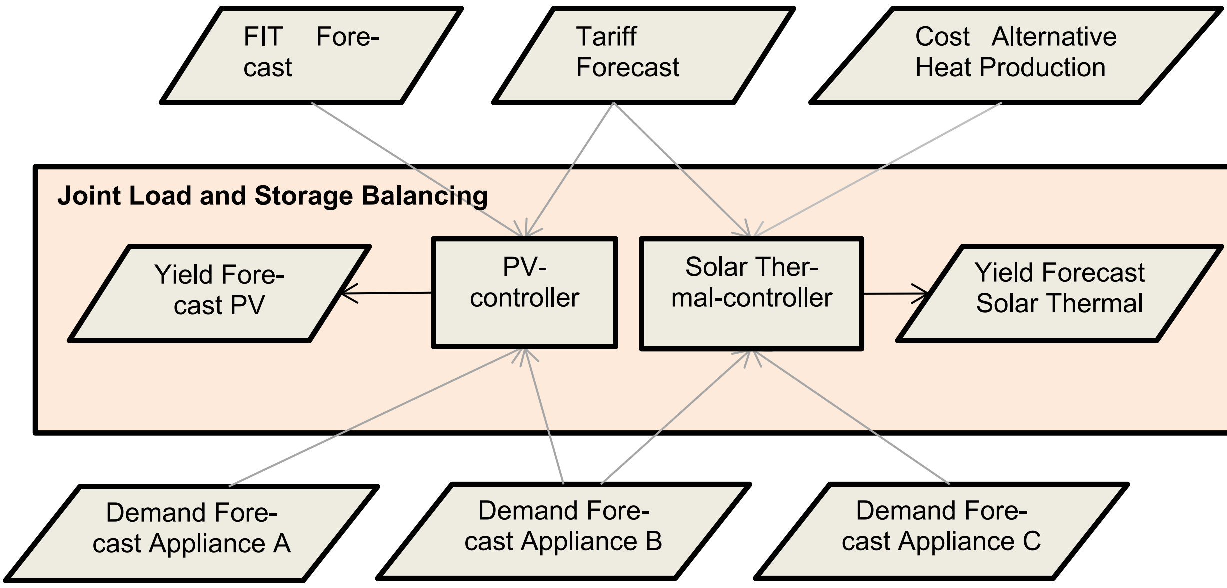

Figure 5 Data and control rationale overarching optimization

For data transmission, a networked system could use existing wireless data transmission networks like 802.11 (WLAN) or power line communication (PLC). Because commonly TCP/IP is used, a wide range of embedded electronics is usable, either combining communication modules with microcontrollers or integrated solutions based on the 8-bit µC 8051, 16-bit C16x or the 32-bit ARM architecture [20]. With 802.11n, there is the possibility to reduce the energy demand while idling [21], thus reducing standby losses of the added communication system.

The system architecture for networked strategic energy management shown in Figure 6 shall consist of three separate layers at minimum. The content of the layers differ, depending on the connected appliances and energy converters available. Switching to Solar DHW or alternative heat production and time shifting and are results of the information processing.

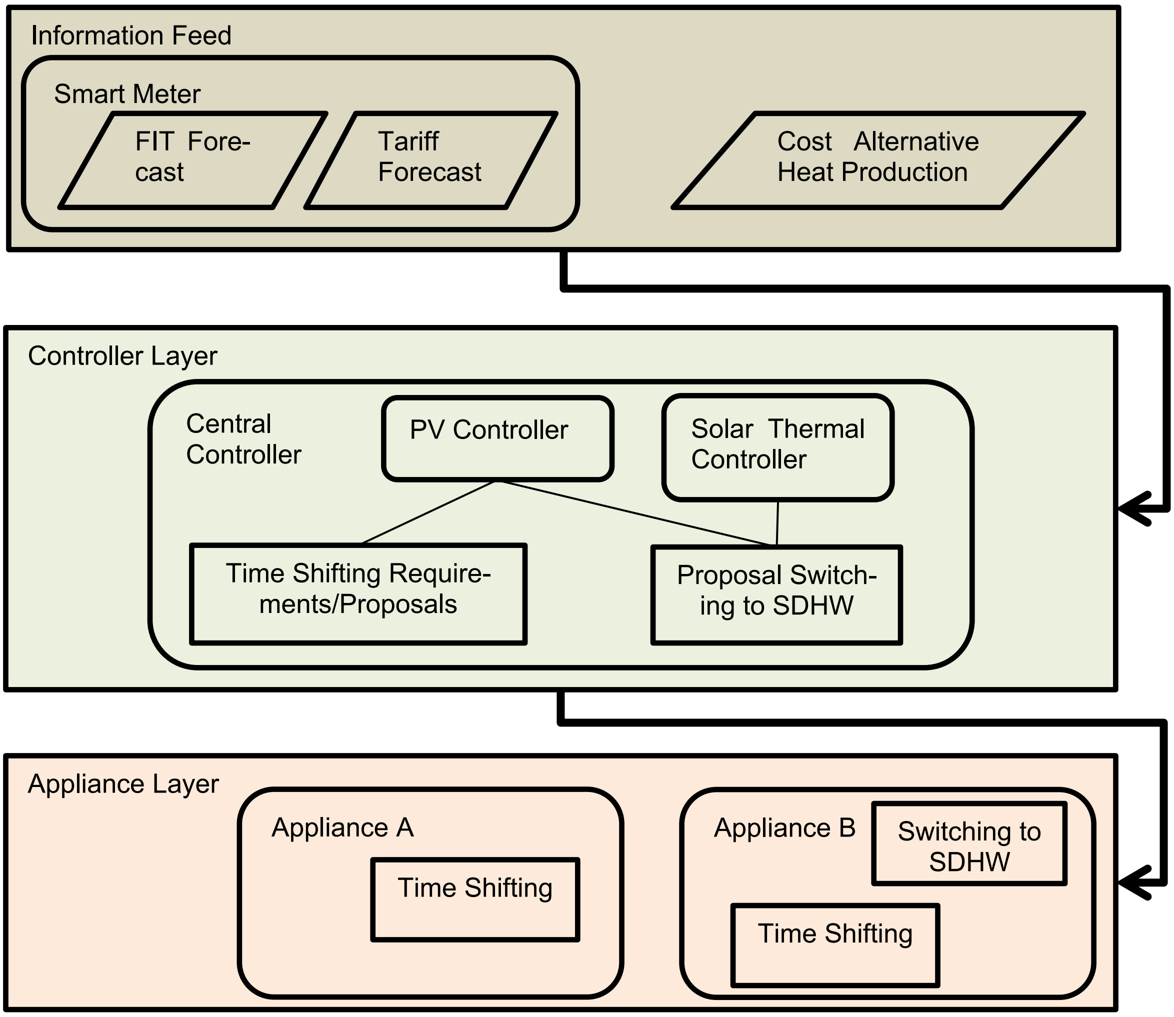

Figure 6 Proposed Strategic Energy Management Architecture

For the function set covering DHW and power control, there could be a direct control of the appliances as shown in. However, the variant shown in Table 1 would require full knowledge of the local process parameters in the appliances to be able take the right decisions centrally. As favourite alternative, the central control could send messages to the appliances desiring a specific behaviour of the appliances only.

Table 1 Discarded Machine-to-Machine (M2M) communication path variant

	Appliance-> solar controller	Solar Controller->appliance
Power	Prognosis of energy demand	Actual tariff high/low – island grids fed from batteries also do have higher tariffs if the insolation is not sufficient Prognosis of available power, based on solar yield
DHW	Required water temperature Required amount of water (Prognosis of energy demand)	Prognosis of available power and maximum temperature, based on expected solar yield

The algorithms to be developed shall account for the likely future solar yield and the tariffs or restrictions of the grid operator. Some Fuzzy-type logic is shown in Table 2.

Table 2 Draft additional Fuzzy rule set for controlling appliances

Issuing Device	**Data used**	**Rule**	**Receiver**
Central Controller	Best-Cost Scenario for PV-power usage	IF FIT lower than actual power tariff THEN propose to store as much energy away as possible, adapting actual power demand of appliances (via voltage control) to the actual yield	Appliances (Refrigerator, DHW-tank)
Central Controller	Expected solar yield using now casts	IF actual yield IS low AND prognosed yield increase high AND no actual power decrease acknowledged THEN propose time shifting	Appliances
Central Controller	Expected solar yield using now casts	IF actual yield IS high AND prognosed yield decrease high AND no actual power increase acknowledged THEN propose negative time shifting	Appliances
Appliance	End time of the process, free buffer	IF proposed time shifting is active AND free buffer is positive THEN speed down or halt the process until the free buffer is consumed	Processes within appliances
Appliance	End time of the process, free buffer	IF proposed negative time shifting is active AND free buffer is positive THEN speed up or start a new process immediately	Processes within appliances
Central Controller	Temperature solar tank FIT tariff or (cut out) Positive power balance (PV surplus)	IF grid feed in tariff is very low AND temperature solar tank is low AND PV surplus THEN substitute DHW use by resistive heating (PV).	Appliances
Central Controller	State of Charge (SOC) battery Expected solar yield using now casts	IF SOC battery is high AND expected solar yield is high THEN increase load	12V Appliances (refrigerator)
Central Controller	Expected solar yield using now casts		Central Controller

6 Discussion of the proposed networked strategic energy management

Solar thermal instalments may profit largely from increased DHW demand, such as generated by adding (dish) washing machines to the list of DHW appliances. Even if additional logic and eventually piping is costly, the use factor for the solar irradiation will climb significantly. However, the need for legionella abatement and the minimum required DHW-tap temperature, especially for kitchens deteriorates the results. So new hydraulic schemes are necessary, which are reducing temperatures in the tank and are based on bivalent ex-post electrical heating, if necessary. Fortunately, washing machines already have that feature built in, and smaller amounts of hot tap water may be heated via flow-through devices. The solar storage tank variant was introduced mainly for room heating purposes [8], but may also exploited for smaller instalments e.g. smaller collector areas, if pre-fabrication and integration of pump and control allows for cost reduction of the indoor unit.

Concluding, making use of excess solar heat in summer requires only small adaptations, if the solar DHW-tank is near the washing machines, including dishwashers allowing separate piping for temperated water. If a solar storage tank is placed inside a heated room, a higher use factor is achieved, because heat losses contribute to the heating demand of the room. Ex-post heating of the DHW before tap is not solving the problem because at 60°C legionella removal needs at least 2 minutes time [22]. So a fresh water heat exchanger would be the better option for low temperature demand as it is the case with laundry machines, showers etc.. Heating to 55°C would add unnecessary losses to the system, even if this done only infrequently to decrease legionella growth. Electric heating power for ex-post heating is low enough, so during the day, excess power from a PV-installation could be used for heating. Preferably, DHW is preheated via heat exchanger in the solar storage avoiding legionella problems allowing using a floating tank temperature below the recommended 60°C [23]. The inclination of the collectors towards the horizontal plane should follow the demand. If absorptive cooling in summer dominates having high temperature demand, then a lower collector angle is recommended, for DHW steeper angles result in higher yields in winter.

Standard solar collectors have selective coating, reducing the heat dissipation during the night. Figure 7 shows the results of a Monte-Carlo (MC) simulation, programmed using Mathcad™. The program is varying randomly ambient and medium temperatures applying a sophisticated thermal model, including differential equations for the fins, comparing the specific cooling power per absorber area.

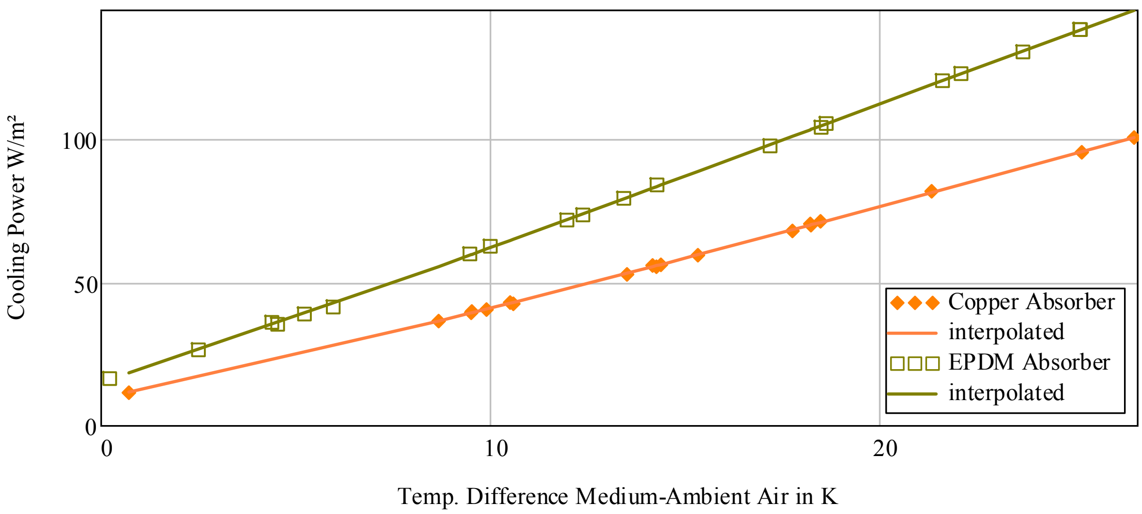

Figure 7 Cooling Power for copper and glazed EPDM absorbers – results from a MC-simulation

The interpolated cooling power curve was used in the authors Mathcad program modelling a collector-DHW-tank-system, developed within the *i.sol.e²* project funded within the Austrian *Neue Energien 2020* programme. However, the temperature of the cooling medium was fixed at 6°C. From simulating one year of operation using data from Klagenfurt, Austria [24], the cooling energy amounts to 66,6 kWh per m² of the absorber and is in the range of 11 to 21% of the DHW yield, depending on the amount of DHW needed. This might be not sufficient for an economic operation, especially in urban centres, because nightly temperatures decrease less. Direct cooling using unglazed EPDM-absorbers would have higher cooling yields, and works best in combination with pool heating having low collector inclination angles. DHW operation seems almost impossible in this setting, even if heating during winter might profit from the large collector size necessary for pool heating because of legionella problems even with additional heating rising the DHW temperature. Polymeric absorbers namely EPDM and Polypropylene PP might be also used in a system consisting of a solar hot water tank and indirect pool heating with a non-freezing medium containing polypropyleneglycol [27] although pumping losses and pool heating efficiency will deteriorate in such a system.

For PV, the economy is good, if no energy storage is involved. By controlling electric appliances using electronic devices in a networked system, the investment is kept low. However, there is a lack of power demand for load management using appliances if larger PV instalments are planned. It might be necessary to feed in part of the power into the grid outside munerative feed in tariffs (FIT) contracts, if power-to-heat is no option. A test installation at the author's premises has validated that using excess PV-power for heating the DHW-tank requires little investment; even 230 V resistive AC-heating elements may be used for DC heating, using affordable voltage adaptation (variable buck boost converter). Concluding, larger PV instalments might only be recommended without good FIT, if larger electric appliances having steady power demand are present like presentation coolers in shops and self-service restaurants or dairy coolers with farmers. House owners providing larger roofs for PV instalments in the multi-kW range and having only a one household may depend from attractive FIT; smaller facilities not able to implement extensive load management may also install electrical storage. Intelligent interaction between demand side (appliances and solar controllers) on the one hand and the supply side (grid operator, boilers) on the other hand requires networking of devices. Single appliances might not be suited being included into demand side management. Opening the focus and introducing co-operation connecting several households is needed, asking also for a legal acceptance doing so.

Figure 8 shows the preconditions and results for three alternatives for strategic energy management with PV as example. The methodology used, analyses four dimensions: the benefit for the environment and users, and the acceptance of producers, grid operators and users. With zero interaction between the appliances and controller the solar use factor is lower compared to the variant with co-operating stakeholders offering open standardized interfaces. Frequency cut-out as it is standard with larger PV-installations, switching feed-in inverters off, will reduce solar use factors.

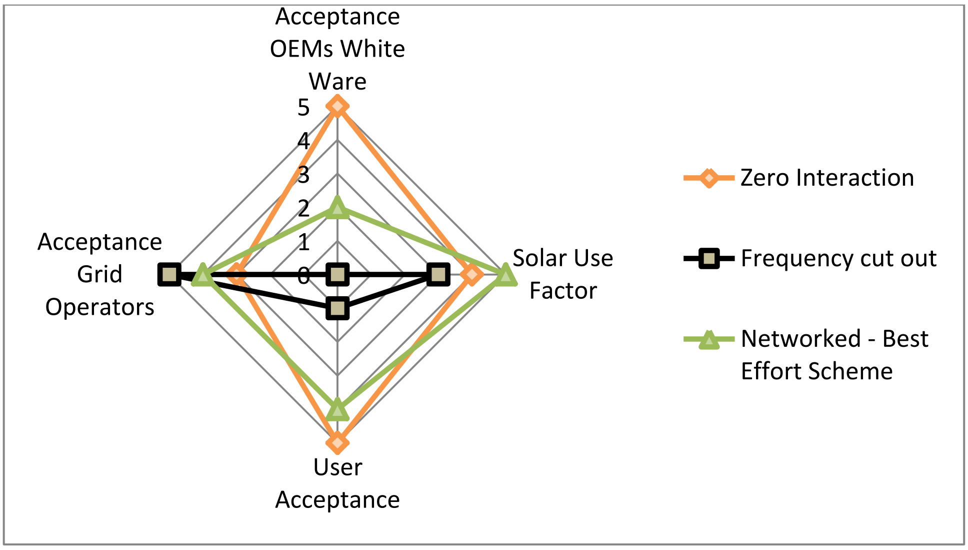

Figure 8 Four-dimensional assessment of connectivity variants

Therefore, a networked best effort scheme will allow keeping the solar use factors high, especially in hybrid PV and solar thermal systems and might gain acceptance with grid operators, and users. Lacking acceptance by OEMs requires however, the set-up of binding standards or inclusion of requirements in funding schemes pushing the implementation of open standardized interfaces.

7 Recommendations

Networking of existing DHW appliances with solar controllers is necessary, even if the DHW appliances are sold together with a fuel-converting unit, comprising a storage tank. Open standards based on affordable local communication networks would allow more market entries and retrofit solutions inserting intelligence into withe ware operation when using solar energy. It is however not necessary to introduce the overhead for a full-blown home automation, to achieve those improvements, but an existing system could be integrated.

A memorandum of understanding shall be issued by the white ware OEMs, defining a short list of communication channels and presenting business models validated in European research projects. The EE-Bus [25] and a wireless communication network extending the existing EN50523-1 Home Automation profile [26] are candidates. The list shall also focus on affordable and ubiquitous networks like WLAN (802.11n with energy management). Strategic energy management tasks need to be pushed more into the CENELEC TC59X/WG7–Smart house by producers of solar and HVAC-controllers. The focus energy saving and demand management needs more political and regulators support to prevail over automation and comfort issues leading sometimes to rebound effects.

Concerning the high pumping energy demand at low temperatures and the heat losses with enhanced hydraulic schemes the above mentioned direct cooling scheme might not generate enough revenues. Unglazed absorbers however might provide thermal activation for buildings, mostly for precooling. Solar thermal installations in Northern Europe are differing much to the ones sold in southern Europe and China being more costly. Adding more intelligence in terms of valves and piping to a networked system certainly increases the solar uses factor but in order to improve the return on investment synergies should be used, and high volume components pre-mounted into modules.

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The potential for domestic hot water tanks and hot-fill appliances to help balance power systems and reduce CO_2 emissions

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Abstract

The European Union is committed to having a 20% share of renewable energy in the overall energy mix by the year 2020. Due to the variable nature of renewable energy supplies, more balancing services will be required to maintain the stability of electricity supply systems. One area attracting considerable attention is the potential to engage domestic customers in providing demand response services. In particular this includes managing electric water heater and wet appliance loads, which together in the UK account for 20% of total domestic electricity consumption.

This article demonstrates a method of time shifting domestic energy use without being disruptive to occupant's usual lifestyles or comfort. A number of dwellings using electric water heating had meters installed to characterise the diversity of usage. Further analysis estimates that more dynamic electric heater switching can reduce standing heat losses from the hot water cylinder compared to how off peak switches are currently operated. Additionally, by replacing conventional cold-fill wet appliances with a new range of hot-fill appliances, resistive heating load is shifted away from the appliance to a hot water cylinder. The utilisation of hot-fill for washing machines and dishwashers was found to reduce electricity consumption on average by 64% and 34% in each appliance respectively.

Findings from this study highlight that electricity and carbon savings can be realised in a significant proportion of UK households; both through the demand response of electric water heaters and by using hot-fill appliances. The relative importance of heat source and appliance usage is examined in order to inform how much electricity can be shifted or reduced in different domestic configurations. A Markov Chain occupancy based model has been developed to simulate the aggregated load curtailment potential from electric water heaters, as well as the thermal capacity of hot water tanks that enables load on response.

Introduction

The European Union [EU] has committed itself to reaching a 20% share of renewable energy supply by the year 2020 [1]. To help meet this target the United Kingdom (UK) Government has set out a plan to replace a number of fossil fuel power plants with wind power generation, which will utilise the strong wind resource found across the UK [2]. It is predicted that by the year 2025 there will be 30GW of wind generation capacity on the GB system, which is equivalent to half of the current maximum system peak demand (~60 GW in winter) [3]. Greater volumes of variable wind generation will likely require additional tendering of balancing services and reduce grid inertia, thus presenting a new set of challenges for the National Electricity Transmission System Operator (NETSO), Distribution Network Operator (DNO), Supplier and Generator to deal with. Already the Great Britain NETSO National Grid plc has reported wind curtailment events and issues with re-dispatching generation to manage high wind generation [4]. In addition to these constraints there is also a need for reserve when wind generation is low or when there are large generation outages. Projections for the use of 'flexible' fossil fuel generation as a backup to wind power, has for instance led to media coverage that suggests large scale wind investment is uneconomical and will not reduce CO_2 emissions compared to using modern Combined Cycle Gas Turbines [5]. Such claims are based on the premise that wind requires far greater reserve sizing compared to conventional generation; however a report commissioned by UKERC finds that any extra reserve required will only be marginal [6]. This debate has importance because of the current dependency on fossil fuel derived balancing services, but as this paper discusses there are opportunities on the demand side that offers an alternative solution.

Unlike energy trading in the open market, ancillary i.e. balancing services are only procured by the NETSO in order to ensure the system remains stable and balanced. Aside from pumped storage hydro that has a total capacity of 2.8 GW and a round trip efficiency of 78% there is no large scale energy storage on the GB power system, meaning conventionally generation or demand must be directly adjusted in response to system conditions [7]. It is estimated that at the moment over 95% of the ancillary services National Grid tender to balance the network come from electricity generation supply [4][5]. Typically these services are derived from either part loaded fossil fuel plant that provide 'spinning reserve' to stabilise frequency, or else by back up generation from Open Cycle Gas Turbines or diesel generators [8]. Therefore there is a significant efficiency penalty and high CO_2 emissions factor associated with the current mix of ancillary services. Annually the cost of balancing the GB system is currently ~300 hundred million GBP, it is expected with the planned changes to generation in the next decade that this cost will run to over 1 billion GBP[10].

Demand side response (DSR) describes the control of demand to balance the power system via ancillary services. DSR requires energy to be converted into its final form or curtailed, rather than being stored in an intermediary form as is the case with large scale energy storage, hence it has a relatively high efficiency. Crucially, DSR can offset the use of carbon intensive balancing services and reduces the requirement for network reinforcement to manage transmission constraints. In recent years the use of DSR by industrial and commercial firms has grown significantly due to the financial gains available on the ancillary services market. This has been partly thanks to the creation of demand aggregators that manage a collection of companies to reach the minimum threshold specified by the NETSO. The greater complexity associated with the domestic sector has limited the use of DSR in households, but as the largest and most volatile demand group, domestic DSR has the vast potential. Many literature sources have highlighted the importance of implementing domestic DSR, including GB's energy regulator Ofgem and GB NETSO National Grid [11][12].

The demand flexibility of individual household appliances is reported in literature, with the greatest potential being attributed to electric storage heaters, electric water heating (EWH), wet appliances and refrigeration. Estimates of the combined domestic DSR capability vary between sources; the Sustainability First group reports the readily available domestic DSR as circa 1 GW [9]. This is readily available because of the Radio Tele-Switching (RTS) technology installed in approximately 2 million households, which permits remote load switching of electric storage heaters and EWH via long wave radio. RTS was developed in the 1980s as a way of providing overnight demand for inflexible nuclear generation. Despite the changes in generation mix overtime, off peak tariffs using RTS still use static charging schedules that results in electric heating load simultaneously switching on.

This paper aims to explore the benefits that can be realised through more flexible remote load switching, with particular reference to RTS controlled EWH. A Markov Chain occupancy based model is presented that simulates EWH load with the UK Economy 10 tariff restriction (10 hour off-park charging schedule). Subsequently a new optimisation algorithm is introduced that attempts to 'flatten' EWH load and provide the greatest demand response availability to the NETSO. The feasibility of shifting washing machine and dishwasher electricity expended by conventional cold-fill water heating to the hot water tank using hot-fill is investigated as a way of enhancing thermal storage capacity and load flexibility. The use of hot-fill is also considered for households benefiting from a local renewable heat supply, which can result in significant CO_2 mitigation.

Domestic electric water heating demand

Electric resistance heaters are a convenient and efficient way of providing direct heat using electricity, however, in terms of CO_2 intensity they are limited by what the electricity generation mix is at anytime. They are used in households for space heating via storage heaters and direct panel heaters and they are also used to heat water in hot water tanks and wet appliances.

Hot Water Storage

The UK has a relatively old housing stock and a diverse mix of heating configurations for the provision of domestic hot water. Condensing gas fired boilers presently dominate the market thanks to their high efficiency and cheaper fuel costs, which at the moment outperform EWH in terms of carbon efficiency. Estimations from stock models suggest that up to 3 million households use EWH as their primary domestic hot water source [13]. As well as offering the potential to act as energy storage for grid connected renewables, hot water tanks can also facilitate the integration of micro renewable heat systems. The UK Government has recently initiated the Renewable Heat Incentive that aims to have 4 million households connected to a low carbon supply of hot water [2]. In the last decade there has been a surge in ownership of combination gas boilers that offer instantaneous hot water without the need of a hot water tank, which may put at risk both the integration of renewable heat systems and the role that EWH can play for providing an ancillary service [16].

Table 1: Summary of household sources of hot water in the UK [13–17]

Heat Source		Current Stock	Annual kWh input	Advantages	Disadvantages
Gas	Combination (Condensing)	11,550,000 (6,312,000)	5,000	Easy to maintain, Less space required, Always hot water available, Low running costs	Low flow rates, Does not offer any storage opportunity, higher water waste, Poorer DHW output when space heating required
	Regular boiler (Condensing)	10,910,000 (2,109,000)	4,840	Option for high flow rates, Relatively inexpensive	Finite storage, Maintenance issues, Space required
Electric Water Heaters		12,000,000 [1]	3,500 [2]	Low capitol cost, Easily maintained, Off-peak option	High running costs, Carbon intensive, Finite storage
Solar Thermal		135,000	-	Running cost free, Zero carbon source, Longevity	Suitable dwelling required, Need additional secondary heat source
Oil		900,000	9,000	Provides heat for dwellings off gas network	High running cost, Carbon intensive

The perceptible lack of literature on the characterising the energy consumption from individual EWHs in UK households deemed it necessary to run a field trial to gain new knowledge. Eight households using EWH for domestic hot water were recruited and suitable equipment was installed to monitor EWH load at a high resolution. Five of the households monitored used RTS controlled EWH that came on at off peak times specified by their tariff. The other households either had their heaters always switched on or else manually used a switch (or boost) to turn on and off power when they required it. This suggests that EWH load may appreciably contribute to evening peak demand on the system. Three of the households reported that because the overnight tariff was not providing them with enough hot water, they had opted to switch off the off-peak heating or else had changed tariffs. Results from the trial have shown that a combination of poor tank insulation as well as RTS times that are the inverse of hot water usage times, are leading to end users either not having the desired hot water or consuming more energy than they need to. By requesting diaries from willing participants it was possible to in some cases disaggregate energy consumption into event types. For example figure 1 shows a household that had the EWH switched on 24 hours a day making it possible to determine time of use and characterise different hot water events. Moreover, when occupants were vacant from their household, the 24 hour standing losses from the hot water tank were recorded. It was found that when this data was compared to manufacturers declared losses; they were consistently higher by 30–60%. Due to the small sample size, as well as other potentially extenuating factors, it is difficult to ascertain whether this is the same for the wider population. The trial results did approximately agree with national data that states the average EWH consumption per household is 3,500 kWh (table 1).

[1] Estimated value of storage tanks with an EWH installed; based on MTP report and DECC information. Majority of these installations are not used

[2] Based on homes using only EWH as the primary heating source, however, many homes use as secondary heating back up

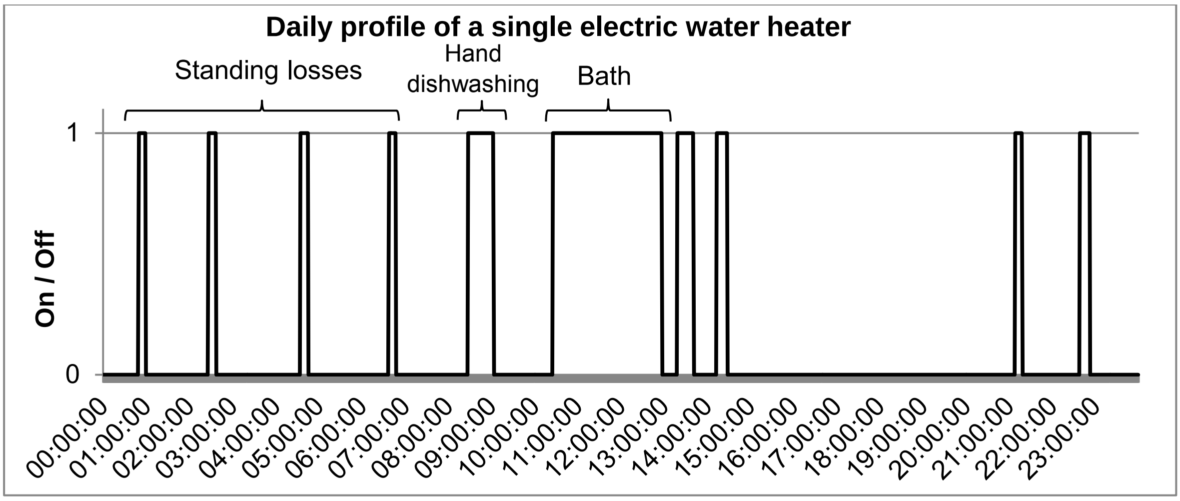

Figure 1: Example of a 24 hour EWH heater profile monitored in situ, with the occupants informing hot water event types

Cold-fill only appliances

Statistics from table 2 highlight the fact that washing machines and dishwashers are a commonly found appliance in UK households that are used by occupants frequently. Equipped with electric heaters rated between 1.8 – 2.2 kW they represent two of the most power intensive domestic appliances. Thanks to EU regulations and technology improvements modern washing machines and dishwashers have become much more energy efficient than their predecessors. It is estimated that 75% of UK washing machines in use are now at least ‘A rated’ [13] (EU labelling scheme requires all new appliances to have an efficiency rating between G and A; where A is most efficient). Nevertheless, washing machine and dishwasher energy consumption remains limited by the fact that these appliances must provide the heat for incoming cold water internally i.e. they are cold-fill only. Data from DECC has shown that the electricity consumption per appliance has reached a plateau since 2008; hence there is no reason to expect that the energy efficiency of wet appliances will significantly improve in the foreseeable future under current legislation. The use of cold-fill appliances limits the DSR capability to direct load switches, either activated by the occupier or by a utility. A recent project named SMART-A involving 9 partners across the EU, focused on this direct appliance control approach [18]. In the SMART-A trial, occupants were requested to set finish times on their washing machines and dishwashers, thus allowing the utility or NETSO to run the wash program at low demand periods or else interrupt during high demand periods. However, the findings did not provide robust evidence that occupants wanted to change their habits. There is also safety and hygiene complications associated with the remote switching of appliances that are may limit its use.

Table 2: Summary of washing machine and dishwasher use in the UK

	Washing Machine	Dishwasher	Total
Number of million units [19]	22,4	9,41	31,8
Average number of cycles [20][21]	260	246	406
Average kWh/cycle	0.75	1.39	2.14
Total kWh per household	195	342	537
Total GWh/year UK [19]	4,368	3,220	7,588
Average Lifespan [21][22]	12 years	13 years	

One solution that is being pursued in order to curtail electricity demand from washing machines is the use of low or cold water temperature programs. For example, many modern washing machines now facilitate a cold water option and detergent manufactures offer products that are designed to work with them to clean effectively. Aesthetically and in terms of performance, the results are encouraging; however, there have been concerns over the effects on hygiene. Research conducted by Terpstra, Bloomfield, Linke, and Lakdawala has suggested that washing at lower temperatures can lead to the survival of various types of bacteria [23][24][25][26]. There is also the question as to whether people in the UK are willing to adapt to cold water washes.

To assess the DSR opportunity presented by washing machines and dishwashers, it is necessary to characterise the appliances' resource usage as to determine the amount of electrical load that can be managed. This was initially achieved by monitoring typical modern appliances in a controllable laboratory environment. Under guidance from the European accredited appliance testing organisation Intertek, energy, water and temperature were recorded at a minutely resolution. Figure 2 displays one of the four selectable dishwasher program's that were measured. In standardised conditions the total consumption figures were in line with those stated by the manufacturer.

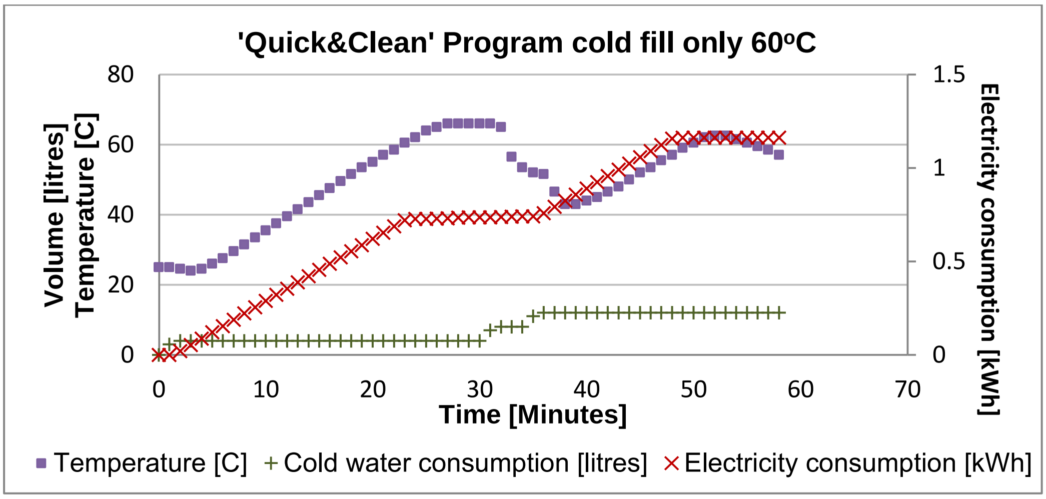

Figure 2: Characterisation of a 60°C dishwasher programme

Methodology to manage loads

A strategy has been developed with the aim of maximising the DSR resource available from hot water tanks, without intervention from occupants or having an adverse affect on their normal usage and expectations. Figure 3 shows a schematic of how the system may operate to lower CO_2 emissions in an efficient manner. By connecting washing machines and dishwashers to a hot water supply it can help integrate intermittent renewable energy both locally connected (e.g. solar thermal systems) and connected to the grid via EWH. The latter is made possible through a load control mechanism, which can be either an existing RTS or potentially a new smart meter system. Whilst it is recognised that renewable heat systems can provide greater CO_2 emission reductions than grid electricity, the focus here is on the latter because of the limited take up of renewable heat systems in the UK at the moment and the more immediate need for low carbon ancillary services on the network.

Flexible electric water heater control

Fundamental to the proposed strategy is the more optimised use of EWH through more flexible load switching. A significant proportion of GB households actively use EWH and many of these households are on time of use tariffs, however, they are currently unutilised for providing ancillary services. Given the current GB grid carbon intensity, Government policy is focusing attention on delivering CO_2 savings by disincentivising EWH and incentivising the use of efficient gas fired boilers and renewable heat systems. It is feasible that solar thermal installations will surge due to their affordability and the proposed financial incentives being offered by the Government. However, these hot water systems will need auxiliary heat for a large portion of the year and are often under utilised in summer when supply exceeds demand. The extra demand created by hot-fill appliances together with the flexibility of EWHs therefore has wider advantages.

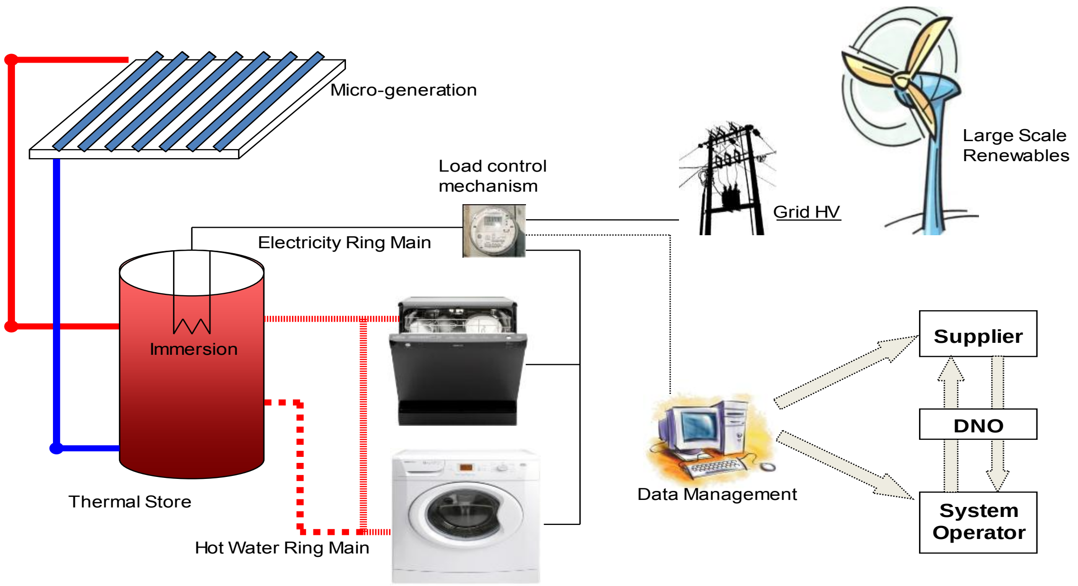

Figure 3: Overview of connections between generation, domestic demand and controllers

Hot-fill washing machines

Washing machines using both hot-fill and cold-fill (commonly referred to as 'hot-fill') were the norm in the UK up until the 1990s. Appliance manufacturers removed the hot water valve for a number of reasons. Firstly, removing the hot-fill valve saved production and maintenance costs. Secondly, at the time boilers were less efficient than they are now and coupled with the dead leg pipe losses to the appliances, there were question marks over the energy efficiency of using hot-fill. Thirdly, at the time these appliances used more hot water for washing than modern machines, which also meant there was less hot water availability for other uses such as showers and baths. This last point was also more relevant in the past when tank insulation was less common and fewer households used pumps or electric showers. The argument for hot-fill vs cold-fill is largely dependent on the domestic configuration they are installed with and in particular to the hot water piping and hot water source.

Working with manufacturer Beko an investigation was carried out into the potential of a new range of hot-fill appliances for the UK market. Starting with existing models that are produced and sold in Turkey, a number of laboratory tests looked in detail at the performance of these appliances. Subsequently, alterations were made to the control software to optimise the benefits of hot-fill intake. This included the provision that the wash temperature is always reached from a lower temperature. In contrast to older legacy appliances that fed cold and hot water simultaneously, logic has been built in that ensures delicate clothes are not subjected to high temperatures.

Results in the laboratory shows that using hot-fill typically reduced appliance energy consumption by between 60-80%. In order to measure the baseline savings from using hot-fill, a 55^{o}C hot water supply was used to represent a typical domestic supply and was compared to using cold-fill only by repeating the cycle with the hot inlet valve switched off. The cold water supply was recorded at 20^{o}C, which is approximately the maximum value it reaches in the UK (in winter temperatures often fall to 5^{o}C). The manageable load was measured in terms of the EWH only as table 3 shows. The results highlight that no electrical heating was required for either 30^{o}C or 40^{o}C programs.

Hot-fill dishwashers

Like washing machines, dishwashers are sold in the UK to be used with a cold fill supply. To test the performance of using hot-fill with dishwashers Beko supplied a model that was designed to take up to a 60^{o}C hot water supply. Table 3 shows what baseline of savings can be expected. The percentage of savings are not as great as is found for the washing machine, however, the magnitude of savings are similar. This is because the electric heater is used to heat the thermal mass of the crockery, which aids cleaning performance and faster drying. Some existing UK dishwasher models present the opportunity to simply swap the cold-feed with a hot fill supply. Nevertheless in the future would be recommendable to have both a cold-fill and hot-fill valve to optimise wash performance and efficiency.

Table 3: Appliance immersion heater time as a function of wash selection and fill type under standard conditions; all washing machine programs were cotton

	Selection				
	30°C	40°C	50°C	60°C	70°C
Dishwasher Cold-Fill					
heater time on wash cycle (mins)			12.4	21.1	25.0
heater time on hot rinse (mins)			15.0	12.5	14.8
Percentage of total consumption from heating			90.1%	96.4%	93.9%
Dishwasher Hot-Fill					
heater time on wash cycle (mins)			8.7	16.3	17.0
heater time on hot rinse (mins)			5.8	5	7.1
Hot water consumed (litres)			16	12	19
Total reduction in heating time (mins)			12.9	12.3	15.7
Washing machine Cold-Fill					
heater time on wash cycle	5.0	9.2	20.9	21.6	
Percentage of total consumption from heater	38.1%	58.7%	72.0%	69.6%	
Washing machine Hot & Cold-Fill					
heater time on wash cycle (mins)	0	0	4.1	6.5	
Hot water consumed (litres)	10	12	14	14	
Total reduction in heating time (mins)	5.0	9.2	16.8	15.1	

Domestic configurations

A critical parameter in the value and efficiency of using hot-fill is the volume of dead-leg between the hot water source and the appliance. There is both the direct loss of heat associated with standing water in the pipes to consider, as well as the issue of cooled down water entering the hot water valve. As discussed previously an optimised appliance control board can ensure that in washing machines the balance between cold and hot water is monitored and adjusted. However with the selection of higher temperature dishwasher and washing machine programs, the volume and temperature of standing water becomes more important because of the limited volume of water the appliances intake. Table 4 presents the scale of energy loss that can be expected through using hot-fill given the normal range of domestic hot water pipe configurations. Also shown is the minimum efficiency of using typical hot-fill programmes as compared to cold-fill only, in terms of the absolute heat energy lost by hot water cooling in pipes. This therefore assumes that the cold water temperature is at 20°C and all the heat left from the standing hot water is subsequently not useful. In reality efficiencies will often be higher than those stated because of lower cold water temperatures and the potential for standing hot water to be used for other events (sink, shower etc). Furthermore it is also assumed that pipes are not insulated, yet insulating pipes can significantly improve the benefits of hot-fill and reduction of pipe standing losses in the household.

The majority of UK households have 15mm diameter pipe installed for domestic hot water. Pipe lengths between appliances and the hot water tank vary between each household and table 4 indicates the normal range that can be expected. An estimation of the pipe length to the appliance can be made if the pipe diameter is known and the time it takes fresh hot water to get to the kitchen sink is measured (assuming appliances are in the kitchen). The key factors in determining whether or not hot-fill will save CO_2 depend predominately on the standing pipe volumes (shown in table 4) and the carbon intensity of the heat source. If the energy used to heat water in the tank comes from a low carbon source the acceptable efficiency of hot water delivery can be lower. If we use an example of a typical UK household configuration that has a gas boiler with 85% efficiency, a hot water pipe diameter of 15mm and a length of 4m to the appliance, it can be estimated that 46% and 30% of the

CO_2 released per dishwasher and washing machine usage can be reduced respectively[3]. It is therefore plausible that a large proportion of UK households can reduce CO_2 emissions by using hot-fill appliances in their current configuration.

Table 4: Hot water distribution efficiency from pipe standing losses when using hot-fill appliances in different domestic configurations

Pipe length to appliance Pipe diameter	2m	4m	10m	25m	25m (with pump)
10mm copper					
Volume (litres of water)	0.122	0.244	0.610	1.53	1.65
WM 40°C min efficiency	62.3%	61.7%	59.9%	55.8%	55.3%
DW 60°C min efficiency	82.5%	80.9%	76.4%	67.1%	74.0%
15mm copper					
Volume (litres of water)	0.282	0.564	1.41	3.53	3.81
WM 40°C min efficiency	61.5%	60.1%	56.3%	48.6%	47.8%
DW 60°C min efficiency	80.4%	76.9%	68.1%	53.0%	63.9%
22mm copper					
Volume (litres of water)	0.642	1.284	3.21	8.03	8.87
WM 40°C min efficiency	59.8%	56.9%	49.7%	34.1%	36.2%
DW 60°C min efficiency	76.0%	69.3%	54.8%	48.5%	48.4%

Hot & cold fill appliances trial

A collaborative project between utility SSE, consultancy Sciotech Projects and appliance manufacturer Beko was setup to investigate the benefits of using new hot-fill appliances. In total 14 washing machines and 11 dishwashers were installed alongside monitoring equipment in fourteen households in order to record resource usage at high resolution. Ten of the households were part of a new net zero carbon homes development (awarded code for sustainable homes level 6) that benefited from a centralised hot water supply fed by a ground source heat pump, evacuated tube solar collectors and a biomass boiler. The other four terraced homes formed part of a retrofit project to reduce CO_2 emissions by 80%, where the hot water supply came from a communal 12m^2 flat plate solar collector with auxiliary water heating from a gas boiler. The objectives of the field trial was to measure time of use, how much end use electricity could be displaced by using hot-fill in situ and whether occupants noticed any significant differences in performance.

In the first 6 months of the field trial the appliances were fed with cold water only to represent the conventional scenario resource consumption. In the subsequent 6 month period hot-fill replaced cold-fill for the dishwasher and the hot water valve was opened on the washing machine. It was appreciated that occupants may change their habits with knowledge that hot-fill was being used, but the trial results as well as a post trial survey indicated this was not the case. From a DSR perspective one of the key interests was when the appliances were being operated during the day. Figure 4 shows a histogram of when appliance programs were started in half hour intervals and includes a sample size of 2366 washing machine and dishwasher washes. It can be seen that these appliances significantly contribute to peak demand, which is typically registered as 07:00-09:00 and 17:00-20:00. Determining the wash temperature was achieved by installing a temperature sensor (thermocouple type K) in the drain house of each appliance. Previous studies into the distribution of washing machine program temperatures selected by end users, has indicated that 40°C was the most popular program followed by 60°C [27][28]. Albeit from a small sample size, our results suggest that occupants are favouring lower temperature washes, which may be as a result of green marketing campaigns and improvements to wash performance at these lower temperatures.

[3] This calculation assumes a 40C cotton washing machine program and a 60C dishwasher program have been selected. Carbon intensity figures of 0.185 kg/kWh for gas and 0.520 kg/kWh electricity are also assumed

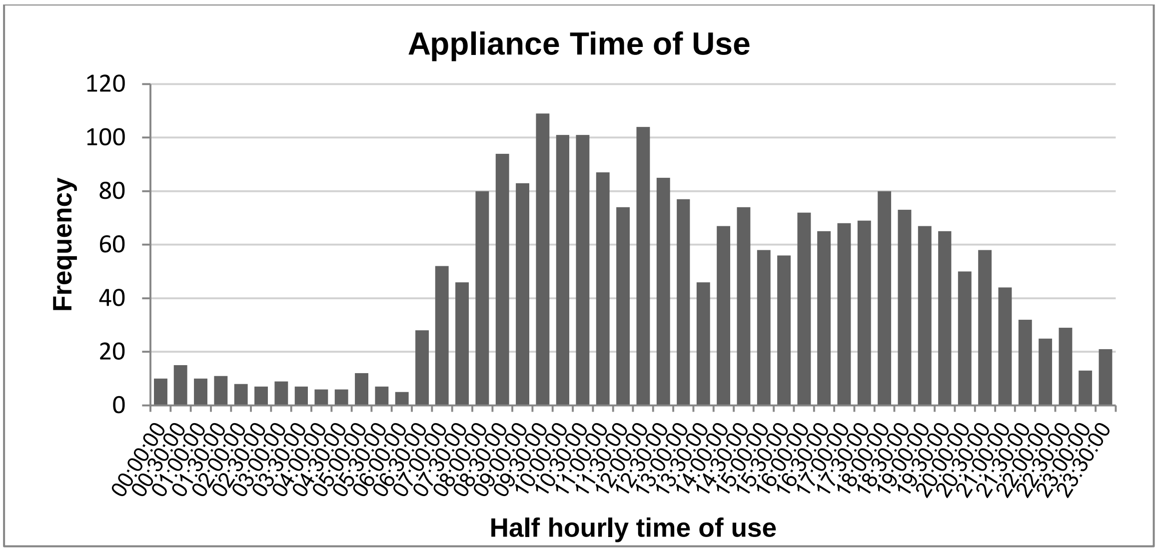

Figure 4: Histogram of aggregated dishwasher and washing machine time of use over trial period

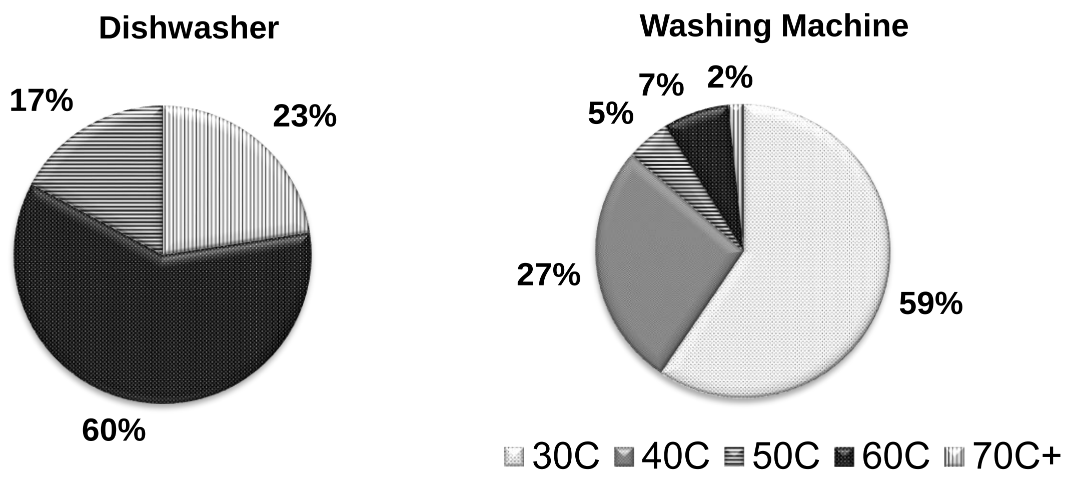

Figure 5: breakdown of temperature selection by occupants in 14 households during the trial period

The 50°C 'Eco' dishwasher program was the least favoured option for occupants due to its longer operation time and poorer wash performance. The post trial survey also indicated that there were no noticeable changes in wash performance with the use of hot-fill. This was an important finding, particularly with the use of hot water for 30°C washing machine programs and suggests that the new control software algorithm is successful.

Table 5: Summary statistics of washing machine and dishwasher usage with and without using hot-fill across 5 households that had a hot water supply temperature between 50C-56C

Appliance	Average weekly usage	Weighted average consumption per use cold fill only	Weighted average consumption per use with hot-fill	Potential annual CO_2 savings
Dishwasher	3.8	1.334 kWh	0.835 kWh	51 $kgCO_{2eq}$
Washing Machine	7.3	0.485 kWh	0.175 kWh	61 $kgCO_{2eq}$
Combined Total	11.1	1.819 kWh	1.010 kWh	112 $kgCO_{2eq}$

It is evident from the field trial results that hot-fill appliance electricity savings vary in proportion to the hot water supply temperature. Initially all ten zero carbon homes were fed with domestic hot water between 33°C – 38°C in order to optimise the performance of the heat pump, however, one household was re-commissioned with a standalone hot water tank using EWH to deliver hot water temperatures up to 55°C. The remaining four households were fed by a communal hot water tank that delivered an average temperature of 54°C. To appreciate the savings that can be delivered by using hot-fill in typical configurations, only the cumulative results from the five households with higher hot water temperatures are shown in table 5. The total number of wash programs in this sample was 1785, with approximately half of these being hot-fill. A preliminary test for the equality of variances indicates the variances of the groups were unequal; therefore a two sample t-test assuming unequal variances was conducted on both datasets. With the use of hot-fill for the dishwasher there is a 95% confidence that average electricity saving per use is between 0.465 kWh (35%) and 0.528 kWh (40%). The addition of hot-fill for the washing machine has a 95% confidence of saving per use between 0.303 kWh (62%) and 0.350 kWh (72%). This shows hot-fill can be used to significantly reduce or manage electric load from the appliance. Using the trial results and assuming a true zero carbon source of hot water, over 100kgCO_2 can be annually cut from households using a washing machine and dishwasher.

Aggregated demand response potential

Using an occupancy based Markov Chain approach a tool has been created to predict the DSR potential EWH can provide in households connected to the GB network. Figure 6 defines the model processes that are used to generate a simulation of EWH load at a one minute resolution over a 24 hour period. The model defines the number of occupants as the initial condition for each household, which is stochastically determined using statistics regarding the GB population. The size of hot water store, insulation type and hot water distribution are determined as a 'property' parameter. Using previous trial data and the data reported by the BRE, hot water demand profiles are assigned to each occupant and the household [17]. This leads to the calculation of initial tank temperature and the control parameter defines what the hot water tank thermostat is set to as well as what the tariff constraints are. For example a household on a particular off peak tariff with RTS may only have their EWH on between the times scheduled by their utility. For simplicity the model assumes the tank is perfectly mixed and calculates the tank water temperature based on the hot water demand, standing losses and the control parameter, which are all at one minute intervals. Once the load profile is generated the process is iteratively completed for any number of households.

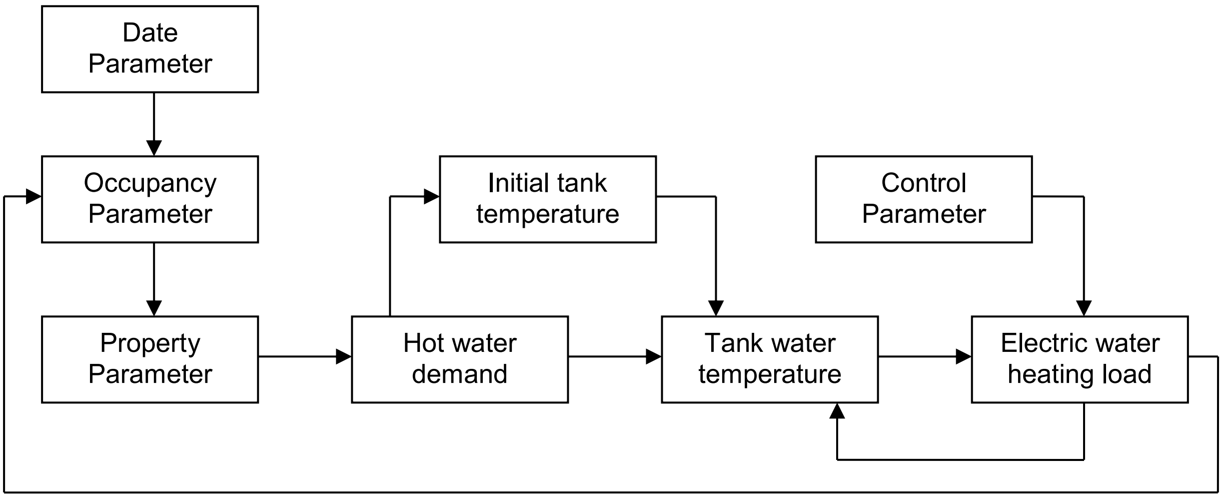

Figure 6: Overview of household model to determine EWH load profile

Electricity suppliers offer a number of off peak tariffs that are predominately designed for customers that have installed electric storage heaters and EWH. One of these, which is referred to as 'Economy 10', is characterised by three on periods, usually between 01:00-05:00, 13:00-16:00 and 20:00-22:00. Unlike similar tariffs that only offer overnight heating, these provide afternoon and evening times, which can provide a better customer service and greater DSR service availability. Households using Economy 10 and EWH may have a variety of metering configurations, here an underlying assumption is made that households have an RTS meter with a separate controllable relay switch for EWH. At the moment broadcasts on long wave radio via the Central Teleswitch Control Unit act to control different groups of RTS meters that each have a unique code. In order to prevent transient voltages on the network, RTS meters are grouped so that they come on +/- 3 minutes of their allotted time. Figure 7 shows a simulation of 500 EWH given the these various restrictions.

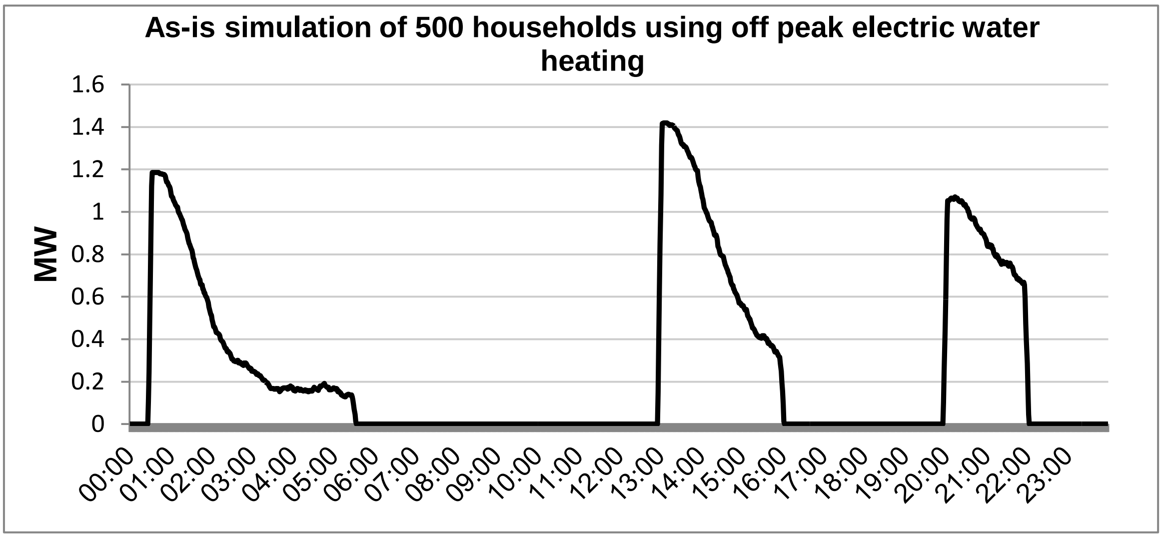

Figure 7: Simulation of as is EWH off peak switching with 500 households on a 10 hour tariff

Naturally as EWHs are all front charged, the aggregation of load has a large peak then will decrease over the allocated time windows as individual hot water tanks reach their thermostat temperature. From both an energy efficiency and ancillary service point of view this is inefficient and unsatisfactory, because firstly end user hot water demand is generally just after the charge windows, and secondly for the NETSO there is less load diversity to call upon at different times. Figure 8 shows how a more optimised i.e flattened RTS schedule can provide more distributed ancillary service availability. This is achieved by delaying or back charging a proportion of RTS meters, based on what their average charge time is historically. Since there is a risk that they may not reach the thermostat temperature in their given window an offset time is also factored in to prevent this happening. A second plot on figure 8 highlights what happens if a new simulation is generated with 500 households that use hot-fill appliances. It can be seen that whilst the trend is very similar there is noticeable additional load in the evening window.

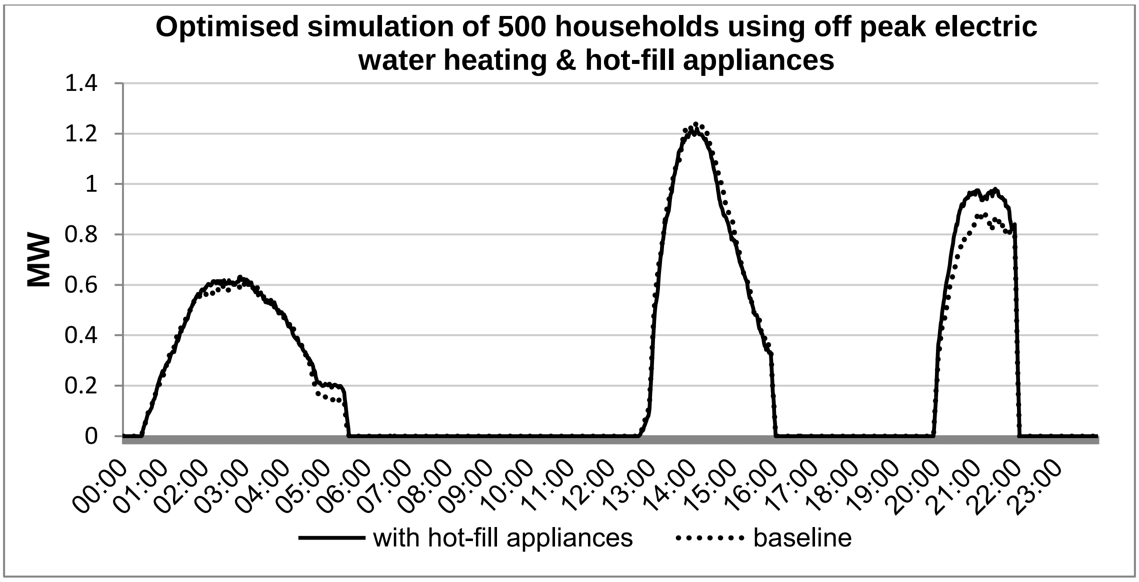

Figure 8: Simulation of 500 EWHs with delay timer logic included; with and without the inclusion of hot-fill to appliances

By re-scheduling the RTS times and providing more distributed load, aggregated EWHs can offer a more improved service for the NENETSO to utilise. Figure 9 includes a conventional load curtailment event in which the EWHs are switched off for 15 minutes at 14:00, which in reality could be the result of a rapid ramp in demand e.g. TV pickup. Logic is added to the radio broadcast to randomly switch EWHs back on over the course of a subsequent 15 minute period, which avoids creating a new transient in voltage. The dashed plot on figure 9 shows how the aggregated storage capacity of EWH varies throughout the day. As greater levels of variable and distributed generation are added to the grid the requirement for switching load on becomes more valuable. Hot water tanks with EWH can provide an efficient resource for storing energy all year round. It is therefore seen how remote switches from either RTS meters or future smart meter systems can enable a highly dynamic domestic DSR resource to compete with other existing ancillary services.

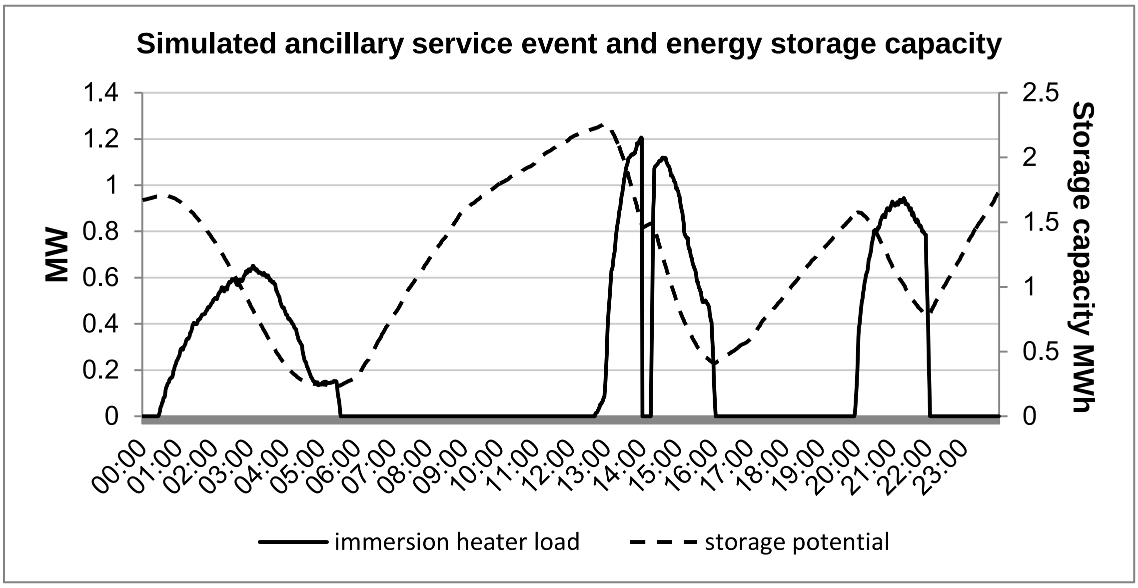

Figure 9: Simulation of the load and energy storage capacity of 500 EWHs with the inclusion of a load curtailment event

Conclusions

A large section of this report has been dedicated to the investigation of hot-fill appliances; both in their ability to reduce carbon emissions directly, as well as their ability to enhance DSR flexibility. The results have indicated that hot-fill washing machines and dishwashers when compared to their cold-fill counterparts can reduce electricity consumption by 64% and 37% respectively. This is particularly of interest to many households that already have renewable heat systems installed or the many more households that will do thanks to the Governments renewable heat incentives. Also noteworthy is the fact that many households with efficient gas boilers may also save carbon by switching to hot-fill.

Presently the GB NETSO depends almost entirely on supply based ancillary services to keep the electricity grid in balance. It is predicted that the volumes of ancillary service required will increase as more renewable energy is connected to the grid. The domestic RTS system offers a viable method to balancing the grid that can potentially reduce carbon emissions by replacing the need for existing and future supply side ancillary services. Engaging with end users in a trial monitoring EWH load has further shown that more dynamic EWH switching may improve energy efficiency, customer satisfaction and therefore reduce the requirement for user activated EWH that appears to contribute to peak evening demand.

Acknowledgements

This work was completed under EPSRC grant number EP/G037787/1 as part of technologies for sustainable built environments (TSBE) centre. In particular I would like to thank those at SSE Plc who were involved with the zero carbon homes development at Greenwatt Way. Peabody Housing Association for allowing us to be part of their retrofitting project and Sciotech Projects for their help with commissioning the monitoring equipment. I would also like to thank Beko Plc for supplying us with the appliances for this project.

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Impact of Residential Demand Response on the Integration of Intermittent Renewable Generation into the Smart Grid

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Abstract

The deployment of renewable generation infrastructures, such as photovoltaic and wind power, have been leading to a dramatically increase on the variability and randomness of energy generation, thus increasing the complexity of the grid management. At the same time, the energy consumption in households has been steadily growing during the last few years, driving the development of real-time monitoring and control systems to achieve energy and costs savings. Such systems could also be used to ensure optimization objectives and to improve the grid reliability, changing the demand profile to match the renewable generation.

The European FP7 project ENERsip has developed a novel energy monitoring and control system integrated at the edge of the service-oriented M2M-based platform for energy efficiency within energy-positive neighbourhoods which provides the required communications and processing capabilities to operate DR (Demand Response) programs with the aim of ensuring the generation and consumption matching. This paper presents the architecture and DR services ensured by ENERsip, as well as the potential impacts of such DR system to ensure the proper integration of renewable generation into the electric grid.

1. Introduction

The efforts to reduce GHG (greenhouse gases) emissions related to electricity generation have been leading to a fast increase in the deployment of renewable generation, in particular photovoltaic and wind power. Such renewable energy sources are being deployed not only as bulk generation facilities but also as distributed local generation facilities connected to the electricity distribution grids or even to private consumption infrastructures [1]. However, wind and solar generated electricity presents characteristics that differ from conventional energy sources. The output of solar and wind power is driven by environmental conditions inherently variable and outside the control of the generators or the system operators. Additionally, supply of power from wind turbines is stochastic in nature and the actual power is more or less proportional to the third power of the wind velocity. The wind output presents large seasonal variations between summer and winter and the variations are also present on shorter time scales, such as on hourly basis. Unlike conventional capacity, photovoltaic and mainly wind-generated electricity cannot be reliably dispatched or perfectly forecasted, and exhibits significant temporal variability. As a result, the proper integration of renewables into the electric grid represents currently a major challenge and new tools are required to ensure the grid reliability.

At the same time, the energy consumption in EU (European Union) households has been steadily growing during the last few years due to the widespread utilization of new types of loads and the requirement of higher levels of comfort and services [2]. Indeed, the electricity consumption breakdown in EU households was recently characterized [3], showing that the loads with the highest share in the households' consumption are lighting and cold appliances (refrigerators and freezers). HVAC (Heating, Ventilating, and Air Conditioning) loads have also shown high consumptions and an increasing penetration rate in households. Other loads, such as washing and drying appliances, have a non-optimized operation, presenting high energy consumption at peak hours (Figure 1). However, if properly controlled, such loads can be used as a DR (Demand Response) resource [4]. Washing and drying appliances can be rescheduled to periods of lower energy consumption (thus flattening the demand curve) or of higher energy generation coming from renewable sources (thus matching consumption with renewable generation and so reducing GHG emissions. The thermal loads (cold appliances, HVAC, and water heating) can be interrupted during shorts periods of time, without major reductions of service quality, to avoid the most unbalanced situations between generation and consumption, compensating the effects of the variability and randomness of the renewable resources availability.

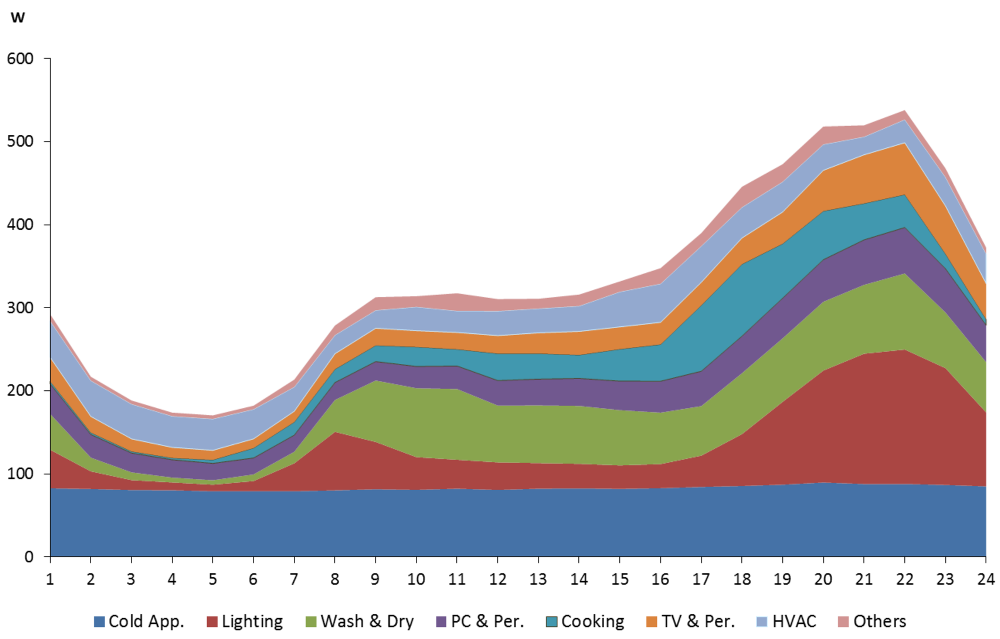

Figure 1: Load profile of an EU average household [3]

As far as security of supply is concerned, the most severe problems due to the wind power intermittence occur in the peak load hours, since the largest part of the available system resources to deal with the intermittence is already used and a sudden reduction of the wind power production can have critical consequences on the system reliability. Thus, instead of acting in the supply side, to avoid the most severe intermittent situations, Demand-Side Management measures can be promoted to achieve consumption reductions and mainly to reduce the peak load. However, in cases of high wind power penetration, the energy consumption reduction during the peak hours may not be enough, because due to the big production variations, such impact in the long term will not solve the supply-demand balance. In such situations it will be very important to have DR technologies to “force” consumption reductions at near real time, in the precise moment in which the critical situations occur [5]. Therefore, the domestic appliances in large scale could have a key role on the integration of intermittent renewable generation.

The case studies of DR in residential and commercial buildings have shown very good results, but with only very limited examples due to the lack of technology [6]. The available commercial solutions provide limited information and control capabilities to the users, with the absence of sub-metering capabilities and local generation monitoring. The communications services to allow information sharing between users and utilities are also limited, not ensuring the required conditions to operate real-time DR programs [7].

To solve these problems, several research and development projects and initiatives are currently underway. This paper is centred on the ENERsip project [8], which aims at developing an innovative ICT (Information and Communications Technology) platform that provides the required communications and processing capabilities to ensure real-time local generation and consumption matching within energy-positive neighbourhoods (i.e., neighbourhoods with high penetration of distributed generation based on renewables). Thus, the main objective of this paper is to present such platform along with the assessment of the potential impacts of residential DR programs to ensure the proper integration of wind power into the electric grid.

The remainder of the paper is structured as follows. Section 2 presents the architecture of the ENERsip system, putting special emphasis on the infrastructure to guarantee the required bidirectional communications for DR. The Energy Services ensured by the ENERsip system are presented in Section 3, highlighting how they can ensure the implementation of reliable DR programs. Section 4 presents a case study where DR actions were applied through simulation in the days with most significant wind output variations. Finally, Section 5 summarizes the paper, emphasizing its main conclusions.

2. Demand Response System Architecture

Figure 2 provides an overview of the system architecture designed to meet the requirements presented in the previous section [9]. Such system architecture is composed of four domains, namely the User Domain, the Information System Domain, the Neighbourhood Domain, and the Building Domain. The User Domain encompasses the UII (User Intuitive Interfaces), which are basically web-based interfaces that allow users to interact in a human-friendly way with the platform (e.g., subscribing some specific appliances to DR programs).

The Information System Domain is where the energy intelligence of the platform resides. It comprises two modules: the PS-BI (Power Saving – Business Intelligence) and the UAP (User Application Platform). The PS-BI is responsible for processing all the consumption and generation data and making the appropriate decisions so that they both are always balanced. The UAP works as a kind of middleware, adapting and serving the information coming from the PS-BI to the UII and vice versa.

The ENERsip system architecture tightly relies on a hybrid and hierarchical M2M communications infrastructure that enables the required real time bidirectional communications between the huge number of devices to be monitored and controlled and the information system and end-users. As it is shown in Figure 2, the Neighbourhood Domain comprises the core of such a M2M communications infrastructure; whereas the Building Domain represents – in ETSI (European Telecommunications Standards Institute) terminology - its “capillaries”.

The Neighbourhood Domain is composed of an M2M Platform and a network of CNTRs (Concentrators). The M2M Platform routes commands coming from the Information System to the appropriate CNTR and forwards data coming from the CNTRs to the Information System. Every single CNTR manages, in turn, a set of consumption and generation infrastructures through the so-called ADR EPs (Automatic Demand Response End Points). Thus, the CNTRs forward consumption and generation data coming from the ADR EPs to the M2M Platform and route commands coming from the M2M Platform to the appropriate ADR EPs.

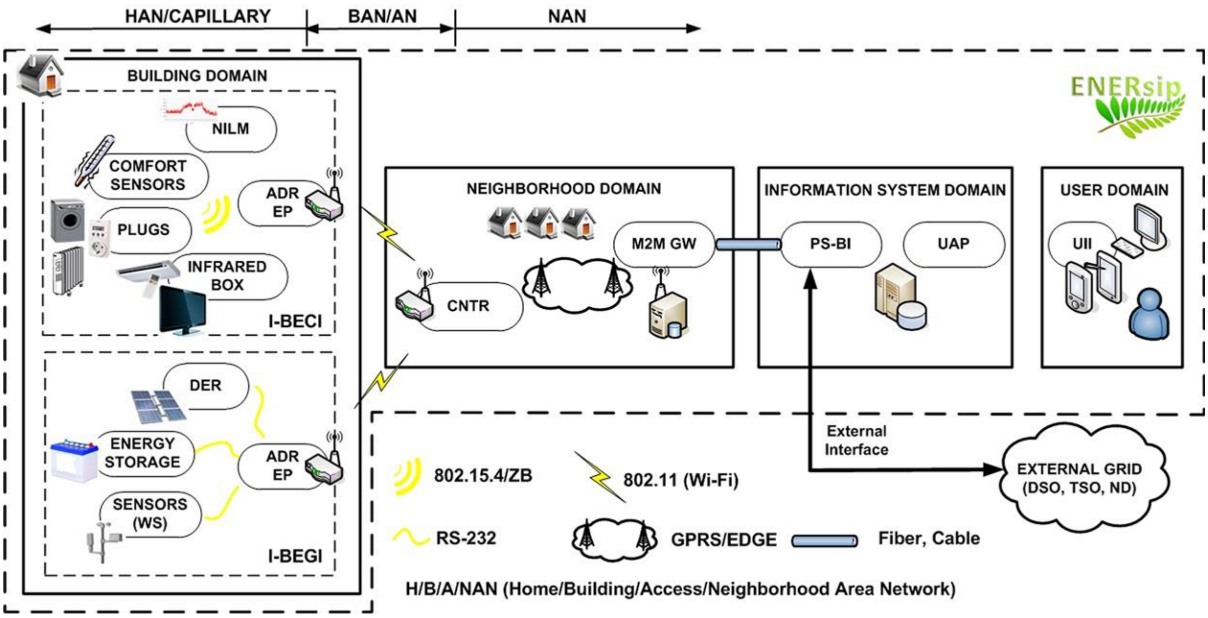

Figure 2: System architecture [9]

The Building Domain comprises the so-called I-BECI (In-Building Energy Consumption Infrastructures) and I-BEGI (In-Building Energy Generation Infrastructures), which represent the in-house consumption monitoring and control system and the distributed generation facilities, respectively. The I-BECI architecture is composed of the following devices: the Plugs, the IR (Infrared) Box, the NILM (Non-Intrusive Load Monitoring) module, the Comfort Sensors, and the ADR EP-C [10].

The Plugs work both as sensors and actuators. On the one side, the Plugs act on the power supply of the appliances by cutting it OFF or ON. On the other side, the Plugs measure the electricity consumption of those appliances and send it to the Information System, allowing accurate monitoring and abnormal behaviour identification. Thus, the Plugs represent a key piece to operate DR programs since they allow having a very accurate view of the consumption (not just at household level, but at the appliance level) and, at the same time, they allow acting on the power supply of those appliances subscribed to such programs. In addition, the Plugs allow the integration of legacy appliances into the in-house monitoring and control system right away, thus enabling energy efficiency and DR before the “smart appliances” come to the market.

The IR Box enables managing the IR-controlled appliances remotely. The IR Box represents a key element of the I-BECI, since it allows remotely controlling HVAC systems (which represent one of the main opportunities to reduce considerably the electricity consumption within households, as it has already been mentioned) and multimedia devices such as TVs or DVDs (which present standby consumptions that mean a relevant percentage of the overall electricity consumption). The IR Box constitutes an important bridge technology, since it allows integrating the huge number of already installed IR-controlled equipment into the I-BECI seamlessly (each IR Box can control all the IR-controlled appliances of the same room). It also ensures a higher degree of control, since with the IR Box it is possible to control the temperature of HVAC systems and not just the ON/OFF control of the appliances as with the Plugs.

The NILM module also represents a key element to enable backward compatibility, since it allows identifying (based on electrical signature) the appliances which are running, even if they are not equipped with a plug with sensor and communication capabilities. The theoretical NILM approach determines when a specific appliance is turned ON based just on its electrical signature, by applying non-supervised Digital Signal Processing methods to the overall electrical signal [11]. However, due to the complexity of such methods, in the ENERsip project the user will inform the NILM module about the appliance which has just been turned ON in order to help it to learn its electrical signature, based on the data received from each plug. The importance of the NILM for operating DR programs is that it helps having a more accurate estimation of the consumption at any time.

The Comfort Sensors measure different environmental variables, such as temperature, relative humidity or CO_2 concentration, which are taken into account when achieving energy savings without compromising the users’ comfort levels. For instance, a temperature sensor can be used to control the HVAC equipment efficiently and to integrate it into DR programs by providing feedback on the actual temperature in a room, allowing actuating on the HVAC consequently.

The ADR EP-C works both as network coordinator and as communications gateway. It is equipped with multiple hardware interfaces and it supports two different wireless technologies: IEEE 802.15.4/ZigBee and Wi-Fi (IEEE 802.11). The Wi-Fi network interface is used to communicate with the M2M communications infrastructure, through the appropriate CNTR, in order to exchange information upstream with the remainder of the platform. The ZigBee network interface is used to communicate downstream with the already introduced I-BECI devices.

The I-BEGI architecture is composed of Energy Generation Equipment, Sensors, and the ADR EP-G [12]. The Energy Generation Equipment includes Photovoltaic Panels and µWind Turbines, which represent two of the most extended technologies in buildings. Both the Photovoltaic Panels and the µWind Turbines are equipped with Inverters, which play a double role: on the one side, they adapt the electrical signal (i.e., converting DC into AC) and, on the other side, they work as RTUs (Remote Terminal Units), measuring some key parameters associated to the generation equipment and sending them to the ADR EP. The Photovoltaic Panels are also equipped with panel temperature sensors, since this parameter influences their performance. Finally, the Energy Meters measure the energy that is generated by the installation.

The main objective of the Sensors is to measure variables related to weather conditions (e.g., temperature, humidity, wind direction and speed, and solar irradiation) and electrical variables (e.g., DC current or voltage, AC current or voltage) and send them to the Information System in order to allow accurate status monitoring and accurate generation forecast, which are two key parameters when operating DR events. The set of sensors in charge of monitoring weather conditions are integrated all together into the same Weather Station and the set of sensors in charge of measuring electrical variables are integrated into the same Network Analyser.

The ADR EP-G is equipped with multiple hardware interfaces and implements multi-protocol features in order to communicate, on the one side, with the I-BEGI equipment (using proprietary application protocols such as Fronius or Davis) and, on the other side, with the Information System through the M2M communications infrastructure (using the ENERsip proprietary protocol on top of Wi-Fi up to the appropriate CNTR, and GPRS up to the M2M Platform). As a result, the ADR EP enables managing in a uniform way the wide variety of devices within the I-BEGI, hiding this complexity and heterogeneity to the Information System, which is able to manage whatever equipment within such infrastructures using the same protocol.

3. Demand Response Services

ENERsip provides DR and energy management services for several groups of end-users, including primarily the owners of residential and commercial buildings, secondly the aggregators of consumption and generation, and finally the DSO (Distribution System Operator). Such users can take advantage of a wide variety of services, such as ‘energy monitoring, visualization, and reporting’, ‘remote access and control of appliances’, ‘load management’, ‘microgrid energy management’ and ‘Distribution System Operation’.

Residential and commercial end-users are provided with a range of ‘energy monitoring, visualization, and reporting’ services, giving them near real-time information about their energy consumption or generation, prices, generation forecast and environmental impact. This information is provided at different levels of granularity, starting from the aggregated data at the whole building level, down to the detailed information about each individual appliance. Such service ensures, not only an increase of the user awareness about the energy consumption (leading to energy savings), but also the identification of the loads available to be controlled by DR actions at every moment.

Using the ‘remote access and control of appliances’ service the residential and commercial end-users can create an initial configuration of the network of energy consuming devices, turn a selected device ON or OFF, or change its properties (e.g., the air conditioning operating temperature). This is not just important to provide to the users the capability to turn OFF the appliances which are unnecessarily turned ON to reduce the energy consumption, but also to perform similar actions automatically through DR events. With such service it is possible to turn OFF remotely any appliances and therefore the appliances used in DR can be easily controlled by the user or by the utility, without the need of any manual operation.

The ‘load management’ is a key service to ensure the implementation of DR. With such service the end-user is able to specify individual devices or groups of devices to be included in the DR program, and consequently, those devices are directly controlled by the ENERsip platform (the user can also manually override it), ensuring the minimization of costs to the end-users (by shifting loads to periods with lower tariffs) and the adequate management of the DR requests received from the utility.

The ‘microgrid energy management’ service works at the local communities and neighbourhoods level, where multiple consumption, generation and storage units might be running. The DSO or the Aggregator receive real-time monitoring data from the consumption and generation sides, at the local communities' and neighbourhoods’ level, improving the balance between generation and consumption in the microgrids. This enables the development of DR actions focused on specific parts of the electric grid in order to ensure the integration of the intermittent distributed generation.

With the ‘Distribution System Operation’ service the DSO receives near real-time information about generation and consumption of electricity in a given location, highlighting the deviations from the expected energy consumption behaviour and providing accurate short-term forecasts of the energy generation. Such information will be very important for the DSO to the planning and dispatching of the generation resources. However, the most important impact of this service is to ensure the required conditions to operate DR programs, namely providing data about the available loads in each neighbourhood, providing communication channels to send real-time tariffs and ensuring the ability to remotely control the appliances according with the user preferences.

4. Assessment of the Impact of Residential Demand Response

To assess the impact of residential DR on the integration of intermittent renewable generation, Portugal was chosen as case study. With 4.5 GW of wind power capacity (which represent 50% of the renewables capacity and 24% of the total installed power) and a yearly generation in 2012 of 10 TWh (20% of the total generation) Portugal already faces the impact of a high penetration of intermittent resources and such a new tool as DR can have a very positive impact on the grid management.

Several extreme ramp rates of the wind power generation were already recorded in Portugal. Therefore, the variations of the wind generation were characterized in order to identify the most substantial variations to be used as case studies. Observing the data from 2007 to 2012, 15 days were found with high variations (reduction of more than 1000 W in less than 8 hours). One of the most severe situations was recorded on 3rd June 2011 with a reduction of 2050 MW in 7 hours, achieving a maximum ramp rate of 560 MW/hour (Figure 3). To the 15 selected days, the impact of DR actions on the residential consumption profile was assessed (in this paper only the data of 3rd June 2011 is presented as example).

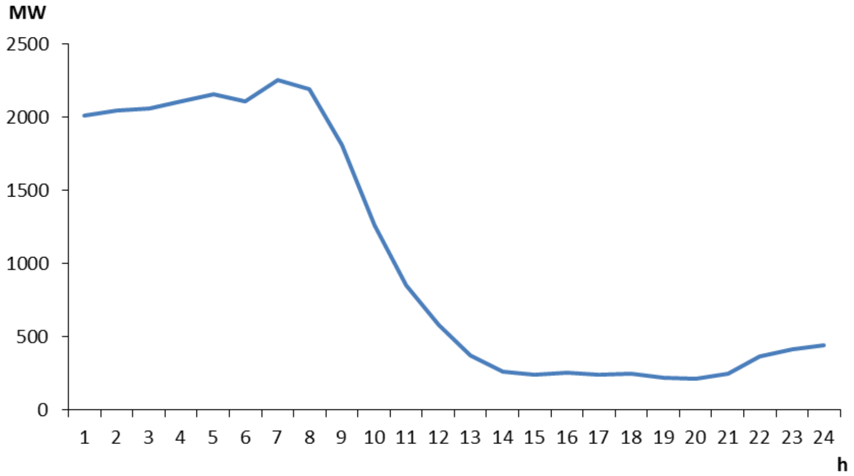

Figure 3: Variation of the wind power generation on 3rd June 2011

To the assessment of the DR, the load profile of an EU average household, presented in Figure 1, was used. In such figure the loads are grouped in 8 types (cold appliances, lighting, washing and drying, ICT, cooking, audio-visual, HVAC and others), but there are available average load profiles, with different load profiles to working days and weekends, from each main appliance [3] out of a total of 26 (freezer, refrigerator without freezer, refrigerator with freezer, lighting of living room, lighting of secondary rooms, washing machine, clothes dryer, dishwasher, desktop PC and monitor, laptop PC, printer, WLAN, router, microwave oven, electric cooker, kettle, TV CRT, TV LCD, TV Plasma, set-top-box, DVD player, HI FI Radio, HVAC, water heater, vacuum cleaner, and phone charger).

Such appliances can be divided into two main groups: controllable and non-controllable appliances. The non-controllable appliances use depends mainly on the user behaviour and its operation cannot be changed without a negative impact on the comfort level. This group includes appliances such has lighting, ICT, cooking or audio-visual appliances.

The controllable appliances can in turn be divided into two groups: reschedulable appliances and interruptible appliances. In the reschedulable appliances the start of the operation can be delayed or anticipated based on the load management requirements. This group includes mainly the washing and drying appliances. The limitations for this operation are mostly set by consumer preferences, but also by technical constraints (e.g., the noise during night operation should be avoided and wet clothes should not be left too long in the washing machine) [13]. ENERsip can ensure the reschedule of appliances with the ‘remote access and control of appliances’ service, controlling the appliance’s operation with the Plugs.

In the interruptible appliances, the appliances are already in operation and under certain conditions it may be possible to interrupt the cycle of operation for a certain period, which is typically restricted for technical reasons. This is typically done with thermal loads such as cold appliances, water heaters and HVAC, which can be turned OFF during several minutes without a major change on temperature. ENERsip can ensure it by using the 'load management' service to select the appliances to control and turning them OFF or ON through the Plugs. The thermal loads can be also controlled by adjusting the temperature to a level with a lower consumption. This can also be ensured by ENERsip to HVAC using the 'remote access and control of appliances' and the Infrared Box to set the temperature.

Considering the ownership rates of each appliance and the total number of households (3.9 millions), each load profile was adapted to the Portuguese reality. Figure 4 presents the load profile of the Portuguese residential sector, forecasted base on the average EU data, in which the loads are divided between controllable and non-controllable. It can be seen that controllable loads present an average power of 657 MW, ranging from 412 to 839 MW.

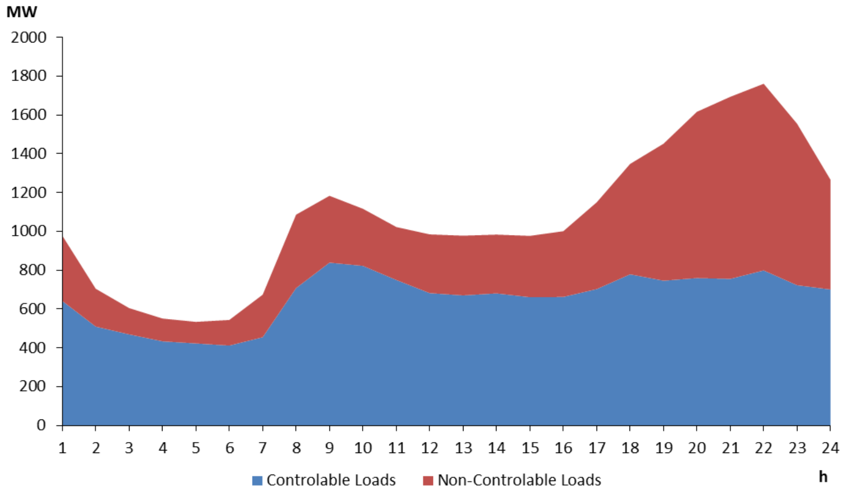

Figure 4: Load profile of the Portuguese residential sector

Figure 5 provides a higher detail about the potential of each controllable load. Cold appliances have the highest and most stable potential with an average controllable load from 268 to 302 MW (average power of 280 MW). The other controllable loads present a potential with higher variations depending on the time of day: washing and drying appliances ensure a controllable load from 17 to 276 MW (average power of 169 MW), HVAC from 36 to 78 MW (average power of 57 MW), and water heaters from 60 to 289 MW (average power of 152 MW).

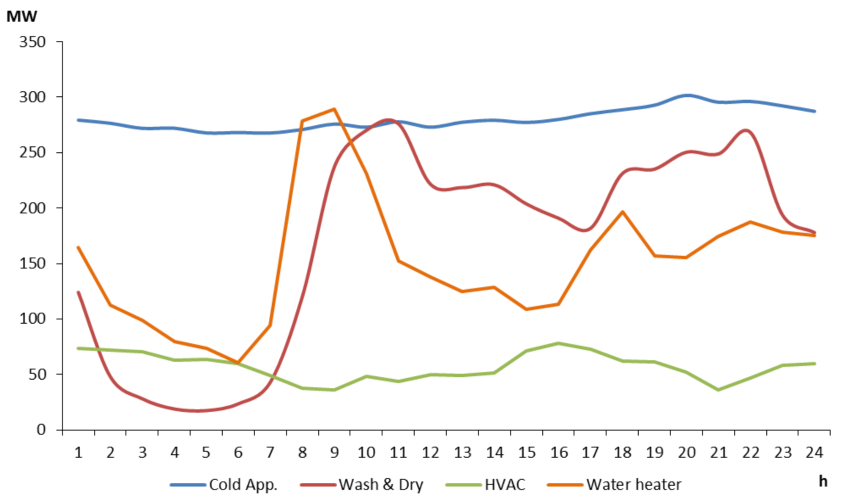

Figure 5: Load profile of the Portuguese residential sector for each group of appliances

A previous study [14] estimated the annual gross economic benefits (including value of avoided CO_2 emissions) of the availability of controllable appliances to purposes of balancing the variable wind energy production. Such benefits strongly depend on the flexibility of the generation system (with a lower benefit to systems with higher flexibility) and were assessed based on the scenarios for the expected shares of different types of power plants for the year 2025. For Portugal, the yearly economic benefits of controllable loads are expected to be from 34.8 to 55.2 €/kW. Therefore, considering an average benefit of 45 €/kW and an average controllable power of 657 MW, the control of such loads can represent an annual gross economic benefit of 29.6 million euros.

Considering a future full penetration of DR systems in the Portuguese households, depending on the time of day, variations of the intermittent generation from 412 to 839 MW can be entirely compensated by DR. The assessed historical data shows that the highest ramp variations are from 350 to 650 MW/hour. However, the controllable load shown in Figure 4 is lower than 650 MW only from 1 to 7 A.M. Since during such time period the wind power variations have a low impact of the electric system, due to the lower demand, the intermittence in that time period can be ignored. Therefore, all the extreme variations observed in the past could be full compensated by DR.

However, the controllable load cannot be turned OFF during all the period of wind power reduction due to technical limitations, such as the temperature change of thermal loads. Therefore, the following limitations were adopted on the assessment: each thermal load cannot be turned OFF during more than one hour; the operation of washing and drying machines can be delayed, but the new operation period should end before 12 P.M. With such limitations two different control strategies are possible: concentrate the load reduction on the beginning of the wind power variation or divide it between the hours were the reduction achieves the highest severity.

Figure 6 present the simulation of the DR impact with the load reduction divided between the hours with the highest impact of the wind power reduction on 3rd June 2011. In such situation the severity of the variation start to be more serious at 11 A.M. and the load reduction was achieved by turning OFF 50% of the thermal loads at 11 A.M., turning OFF the remainder 50% at 12 A.M., and delaying the start of operation of all reschedule appliances which would start the operation at 12 and 13 P.M. With the implementation of DR was possible to compensate the wind power variation during such period.

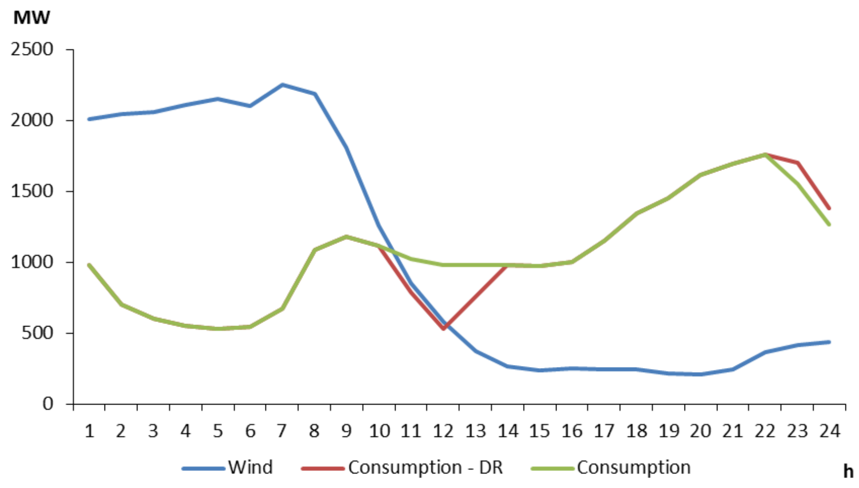

Figure 6: Impact of DR on the period with higher impact of wind power variation (3rd June 2011)

However, the main problems to the electric system occur in the beginning of the variation, due to the need of a fast answer from the system to compensate the lost generation capacity. If the system do not have enough flexibility to react immediately, e.g., with the increase of hydropower generation, it can have critical consequences on the system reliability. Therefore, concentrating the load reduction on the beginning of the variation to give enough time to increase the generation ensured by other sources is usually the best solution to avoid major reliability problems.

Figure 7 present the simulation of the DR impact with the load reduction concentrated on the beginning of the wind power variation. This was achieved by turning OFF 100% of the cold appliances and 30% of the water heaters during the first hour and using the remainder controllable load during the second hour.

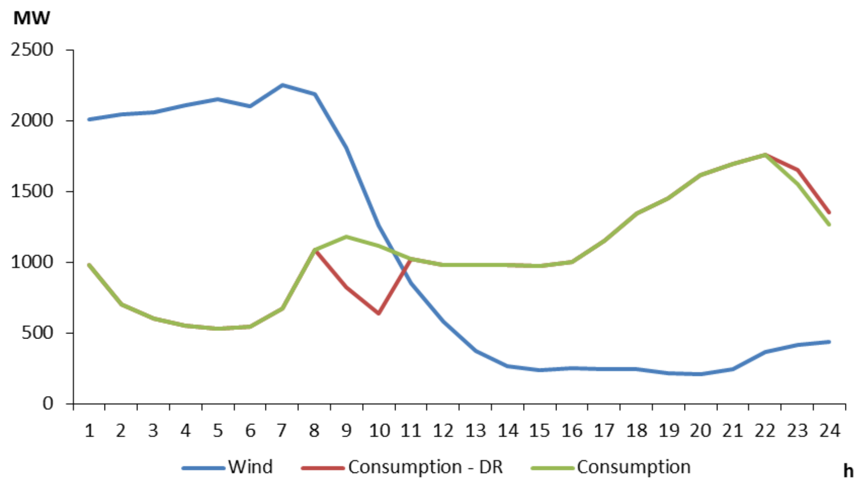

Figure 7: Impact of DR on the beginning of wind power variation (3rd June 2011)

As can be seen in Figure 8, the reduction capacity is enough to cancel the wind power reduction during the first hour and attenuate it in 87% during the second hour, ensuring the needed time to adapt the generation mix.

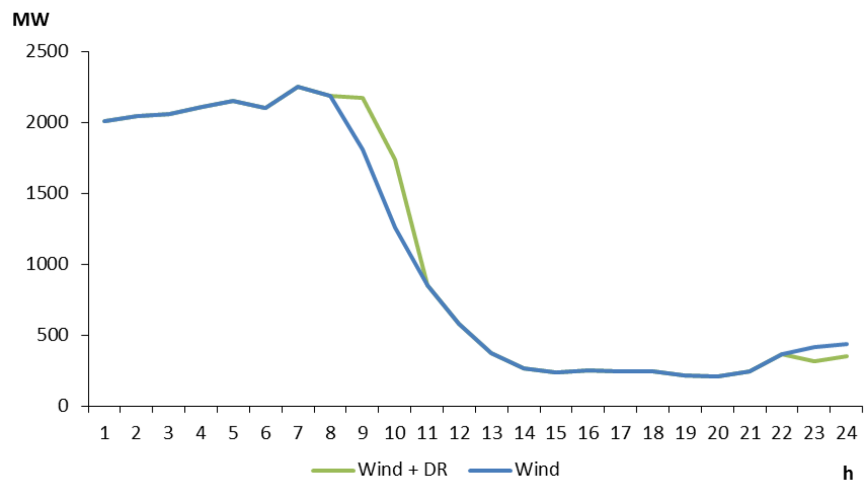

Figure 8: Compensation of lost wind power with DR

5. Conclusions

This paper presents the monitoring and control platform designed and developed under the EU FP7 project ENERsip, whose main goal is to optimize, in near-real time, and to save energy by remotely monitoring, controlling and coordinating energy consumption and generation within the energy-positive neighbourhoods of the future Smart Grid. The proposed system was already integrated and validated under real conditions and all the test cases were successfully completed proving the effectiveness of the system. Such platform ensures the needed conditions to guarantee local energy generation/consumption matching and to operate large scale DR programs, which can provide very important benefits to the electric grid management.

In addition, the paper assesses the impact of the implementation of residential DR (as enabled by ENERsip) on the large scale integration of intermittent renewable generation into the Portuguese electric grid. The load profile to the controllable appliances was determined and used to simulate the possible changes on the load diagram during the wind power variations, considering the reschedule of washing and drying machines and the interruption of the operation cycle in cold appliances, water heaters, and HVAC. It was demonstrated that the total DR potential is enough to compensate all the most extreme historic wind power variations during the first hours (tested with the 15 days with higher wind power variation during the last five years), ensuring the needed time to adapt the electric system to the new generation levels and therefore avoiding the most critical situations.

It can be concluded that domestic appliances, if properly controlled, can be a valuable tool to the electric grid management and consequently to promote the renewable generation with positive environmental and economic impacts.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement nº 247624. The authors would like to thank the whole ENERsip consortium: Amplía Soluciones S.L, Honeywell SPOL, IEC, ISA, ISASTUR, ISR-UC, MSIL, TECNALIA, UC3M, and VITO, for the valuable discussions and collaboration. This work at ISR-UC has been framed under the Energy for Sustainability Initiative of the University of Coimbra and supported by the FEDER/PORC FCT Grant CENTRO-07-0224-FEDER-002004 (EMSURE – Energy and Mobility for Sustainable Regions).

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Voluntary Peak Load Curtailment: What Drives Household Performance?

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Abstract

The price of energy at critical peaks is an increasing concern in Europe as peak demand reaches ever higher levels. This is also the case in California. What happens when a utility asks everyone to reduce his or her energy use for specific days and hours and then pays bill credits for measured reduction? Do customers get the message? Do they understand it? And, what do they do?

This paper presents the results of a process evaluation of San Diego Gas & Electric's (SDG&E) Peak Time Rebate (PTR) program—an initiative that provided bill credits, but no penalties, to customers who reduced their electricity use during specific event periods. Post event surveys were designed to assess overall awareness among several key customer groups and to find out what, if any, actions these customers took in response to a request to reduce their energy use. In addition to the post-event surveys, the project included a survey to understand overall program awareness and perceptions of these requests.

This evaluation used post-event surveys to assess event awareness, actions, and attitudes among several customer groups. Results indicated that customers have high levels of awareness around the overall concept and language used for event days, but that recollection drops off precipitously as respondents are asked about specific event dates. Event awareness was higher among those who had opted-in to receive alerts, and among those who receive electronic communication from SDG&E. Classification And Regression Tree (CART) analysis confirmed that opting-in for an alert is an important correlate of curtailment.

Introduction

Utilities around the world are investing in advanced metering infrastructure (AMI), or digital Smart Grid meters, to replace old analog meters. These digital meters allow utilities to see minute patterns of consumption, in addition to the analog measures of volumetric consumption. According to a 2012 Federal Energy Regulatory Commission survey, the penetration of Smart Meters in the U.S. is currently 23%. [1] Investments in digital meters have been justified for the potential they bring for enhanced visibility into energy use patterns—for both utilities and end-use customers. This information is expected to be potentially quite valuable in the design and delivery of energy efficiency and demand response programs (collectively referred to as demand-side management, or DSM in many parts of the U.S.).

Utilities in the U.S. are increasingly offering demand response programs as a strategy for avoiding expensive investments in new generation or high priced market power. Demand response programs are designed to cause a reduction of energy use during peak demand periods, where market prices for power tend to be the highest, and the least cost-efficient power plants are brought online.

SDG&E, with Smart Meter infrastructure fully deployed to all 1.3 million residential customers, has launched several programs designed to encourage behavior change at critical periods of peak demand by leveraging the enhanced visibility possible from linking detailed consumption data with web-based displays of consumer-specific information. This paper presents the results of an evaluation of the 2012 PTR program, which offered bill credits for measured reductions in electricity use during specific time periods, but did not asses penalties for non-curtailment.

One of the key characteristics of any Smart Grid demand response program is the program's mix of direct load control (DLC) devices and end-user behavior to reduce household energy use during specific event periods. SDG&E, like other utilities, has both DLC and behavior-based programs. [2, 3] One of the limits of DLC programs is obtaining permission from individual residential customers—getting them to agree to allow the utility to control major equipment (typically air conditioning settings) during critical peak periods. These periods often occur during high temperatures; therefore, participants can experience thermal discomfort. In addition, the requirement to have air conditioning equipment can exclude large sections of the market, even in sunny California.[1] PTR, a voluntary, behavior-based program, allowed any residential account to earn bill credits for energy saved on event days.

Like most utilities, SDG&E offers residential customers an opportunity to pay utility bills and manage accounts using an online system called 'My Account.' Once a customer has set up an account with SDG&E, they can access up to 25 months of account activity and information and have the potential to access detailed consumption data as uploaded by SDG&E's Smart Grid infrastructure. About half of SDG&E's 1.2 million residential customers have registered for the 'My Account' system. During the 2012 PTR season, SDG&E sent demand response event notification messages to all email accounts associated with 'My Account,' making this status an important variable for the purposes of the PTR evaluation.

Peak Time Rebate Overview

SDG&E's 2012 PTR rate[2] gave a bill credit to all residential and individually metered small commercial customers who reduced their energy use when requested by SDG&E during a specific time. Customers were paid 75¢ per kilowatt-hour (kWh) reduction between the hours of 11:00 a.m. and 6:00 p.m. on event days, and penalties were not assessed for households that did not achieve measurable reduction of electricity usage. To encourage customers to embrace technologies that enable automated demand response, customers enrolled in the Summer Savers (an air conditioning cycling program with DLC) earned a premium incentive of $1.25 per kWh reduced. Using SDG&E's Smart Grid infrastructure, bill credits were calculated based on measured reduction in electric usage on an event day relative to an established customer-specific reference level for that day.

PTR events were called based on a combination of assessed power system capacity, expected demand, and capacity bidding triggers, which were based on the forecasted temperature and expected system load at 2:00 pm. In addition, California operates with statewide Flex-Alert[3] days that are independent of PTR's Reduce Your Use (RYU) days (weather or system events that cause capacity constraints in Northern or Central California do not necessarily constrain the San Diego system). Regardless of the location of power system capacity constraints, alerts for Flex-Alert days were reported in San Diego media. To minimize the potential confusion with Flex-Alert days, PTR staff decided to call RYU days on all Flex-Alert days during the demand response season.

SDG&E called a total of seven RYU day events during the summer of 2012. Customers could sign up in advance ("opt-in") to receive alerts either by email or text message. In addition to the opt-in alerts, SDG&E sent alert emails to all customers with 'My Account' and announced events broadly using mass media (including television and radio announcements), social media, and press releases carried by other media outlets.

Evaluation Objectives and Methods

Research Into Action, Inc. conducted a process evaluation of the 2012 PTR rate. The objectives of this process evaluation were to:

- Document and assess the implementation process and identify opportunities to improve effectiveness of the PTR program;

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[1] Reflecting the clustering of population in the mild costal climates in California, U.S. Census estimates that approximately 34% of residents in the San Diego Metro Area have central air conditioning.

[2] This program was authorized by the California Public Utilities Commission in the SDG&E rate design proceeding by decision D-08-02-034.

[3] Flex Alert is an urgent call to Californians to immediately conserve electricity and shift demand to off-peak hours. Flex Alerts are issued by the California Independent System Operator, responsible for providing early warnings of possible electricity outages.

- Assess customer awareness of the program including their perceptions of, and responses to, curtailment requests; and
- Evaluate the effectiveness of the messaging used in the program and suggest improvements to increase customer awareness and understanding.

To inform the evaluation, the research team conducted interviews with program staff, three surveys of post-events, a general survey assessing residential customer perceptions of PTR, and three focus groups.

Data collection centered on several aspects of awareness and understanding and included questions to assess:

- Overall awareness of RYU events
- Customers' sources of awareness
- The relationship between opting-in for an event alert and awareness or curtailment
- Customers action in response to event requests
- The extent to which reported behavior correlates with event performance

Table 1 provides the survey groups for residential survey data collection activities. All four surveys included Alert, 'My Account,' and No 'My Account' groups. In addition, the August and September surveys included samples of participants in two other SDG&E programs: San Diego Energy Challenge (SDEC), where participants signed up to compete to reduce energy use and win prizes for themselves and local schools, as well as receiving PTR alerts, and Summer Savers, a DLC program cycling air conditioners in exchange for an annual incentive..

Table 1: Residential Survey Groups

Survey Type	Month Collected	Mode	Alert	My-Account	No MY-Account	SDEC	Summer Savers
Post Event	July	Phone	X	X	X		
	August	Phone	X	X	X	X	X
	September	Phone + Web	X	X	X	X	X
General	December	Phone	X	X	X		

The availability of actual consumption data from SDG&E's AMI provided the evaluation team with an opportunity to compare findings from the process surveys with actual curtailment performance. The evaluation team used CART analysis to assess the key drivers behind consistently measured curtailment during event periods and identify variables that could allow SDG&E to more effectively target RYU messaging and encourage participation among those most likely to respond. CART - also known as recursive partitioning - builds a classification or regression model represented as a binary tree by recursively splitting the cases into two groups using the split that maximizes the variance explained. The overall model conveys the relative predictive strength of the independent variables relative to the outcome. The CART analysis and results are discussed in more detail below.

To facilitate understanding and simplify this paper, only the results of the September post-event survey are included here.[4]

[4] For a copy of the complete report and results of all survey waves, see the final report at http://www.calmac.org. Study ID SDG0269.01

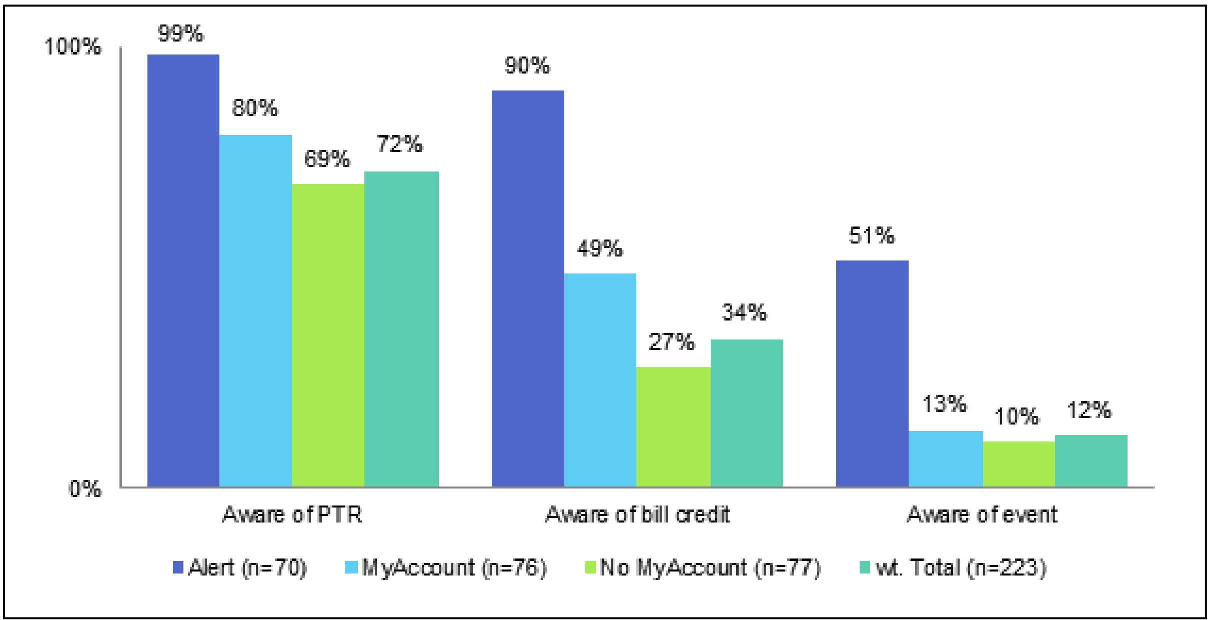
Event Awareness, Behaviors and Attitudes

Surveys revealed that awareness of the overall RYU message and concept was high (Figure 1), but that awareness decreased when respondents were asked about more detailed programmatic features (such as the bill credit opportunity or specific event call dates). Unsurprisingly, those that had voluntarily opted-in to receive an alert on event days also had the highest level of awareness.

Event Awareness

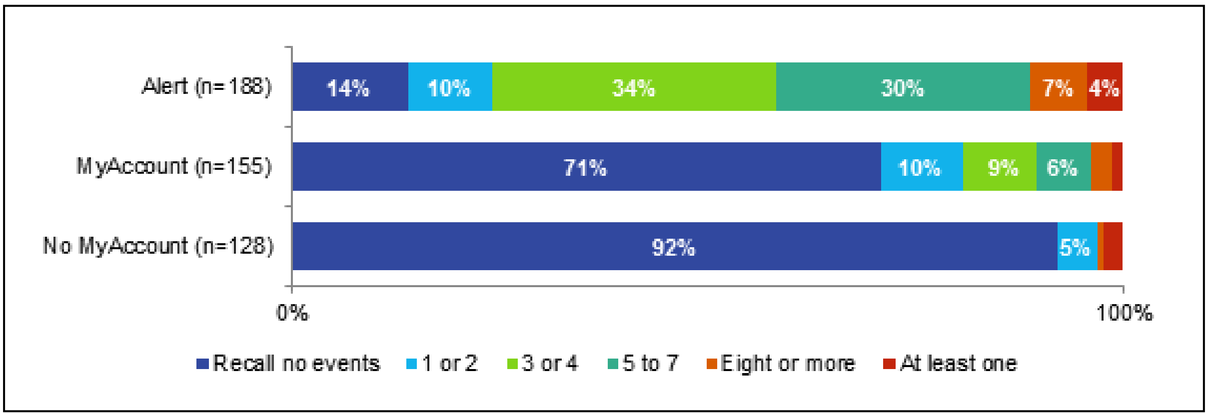
While general awareness was relatively high, awareness of programmatic or event-day details appeared to be driven by Alert/My Account status (Figure 1). Awareness of the RYU requests was relatively constant across the post-event surveys, where the lowest levels of general request awareness were over 65%, and the highest were nearly 100%. Respondents were less aware of programmatic details such as the opportunity to earn bill credits and were often unable to recall the specific date of the RYU event.

Figure 1: Awareness of RYU days, Bill Credit, and Specific Event



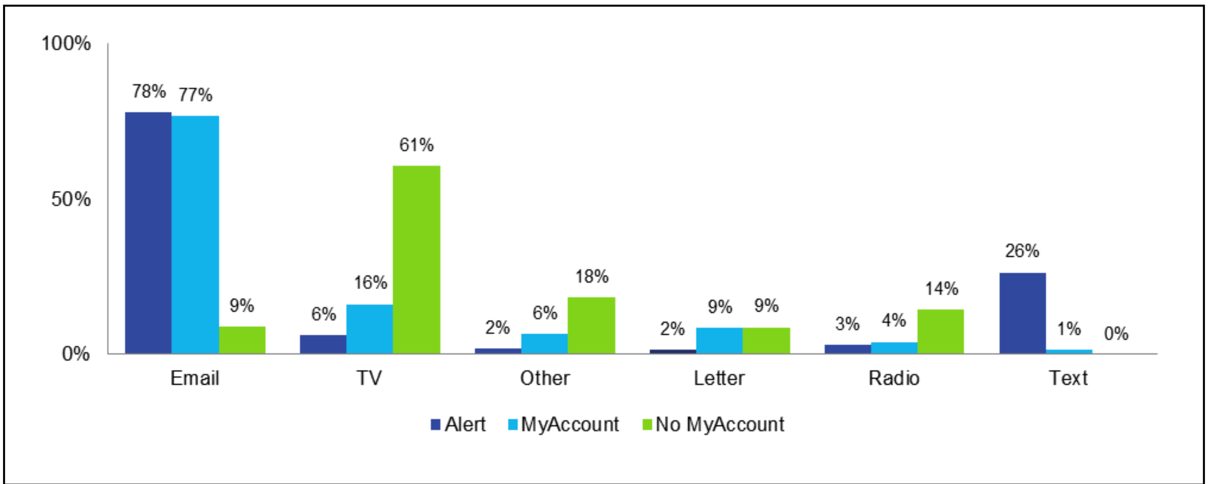
The general program survey results reveal differences in event awareness across groups (Figure 2) and, again, point to the importance of opting-in to receive notification. Approximately three months after the last event, over 90% of customers without My Account were unable to recall a single PTR event. In comparison, 86% of Alert group contacts recalled at least one event.

Figure 2: Number of RYU Events Recalled



The evaluation also found differences between the groups around the sources of awareness and desired method of notification, particularly between those with My Account and those without (Figure 3). Email was the best source of information for My Account customers, while those without My Account were most likely to report hearing about a RYU day on TV. Alert status was again an important variable in both level of awareness and overall engagement with PTR and SDG&E messaging, as was My Account. The fact that customers with My Account registered their email addresses with SDG&E made them easier to reach and more likely to be aware of programmatic details than those without My Account.

Figure 3: Top Methods of Event Awareness (Multiple Responses Allowed)[5]



The preferred means of notification also differed across response groups. Alert group contacts and My Account contacts preferred email and text message as means of awareness, while those without My Account preferred mail and TV. The large portion of the group without My Account that preferred notification by direct mail indicated that this group might be difficult to reach for the short-notice events that characterize demand response.

[5] Asked only of event-aware contacts.

Figure 4: Preferred Method of Alert (Multiple Responses Allowed)

	ALERT (n=188)	MYACCOUNT (n=155)	NO MYACCOUNT (n=128)
Email message	86%	71%	40%
Direct mail	26%	37%	55%
A text message	53%	50%	33%
TV announcement	25%	30%	41%
An automated phone call	29%	30%	35%
Radio announcement	19%	26%	27%
Newspaper articles	10%	12%	21%
Information on the SDG&E website	26%	21%	11%
Facebook, Twitter	18%	22%	9%
Other web news sources	10%	19%	9%

Event Behaviors

Only those aware of events were asked more detailed questions about event engagement. Among these contacts, a majority reported making an effort to reduce their energy use during even periods (68% overall, including 77% of alert group contacts). Those contacts who reported making an effort on an event day reported what actions they took to save energy (Table 2). Among those who made an effort to reduce their energy use, 59% reported turning off lights in unoccupied areas of their home, 56% said they avoided doing laundry during the event time, and 54% turned off or adjusted their air conditioner. Other actions mentioned included delaying running the dishwasher (38%), unplugging unused electronics (35%), leaving home (32%), and shifting cooking times (24%). An additional 50% reported they also “just tried to use less energy.”

Table 2: Actions Taken During RYU Event

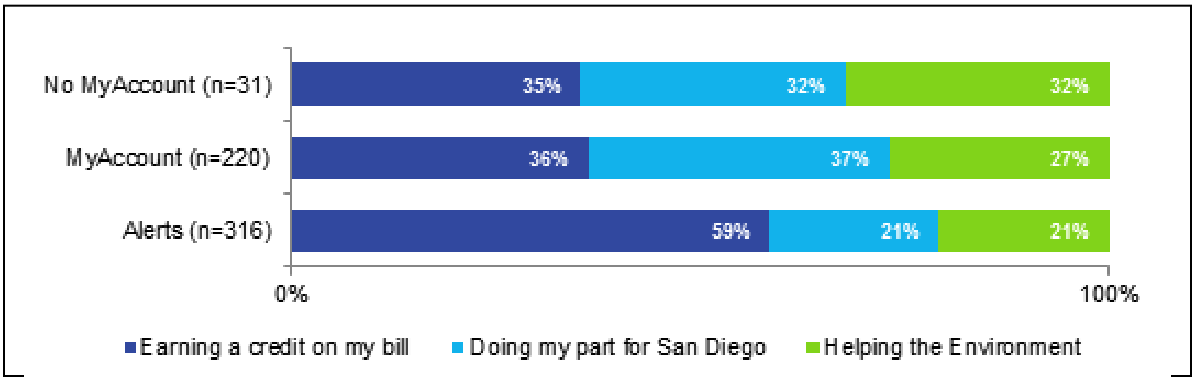
Action	Percent (n=687)
Turned off lights in unoccupied spaces	59%
Didn’t do the laundry	56%
Turned off or adjusted air conditioner	54%
Didn’t run the dishwasher	38%
Unplugged unused electronics	35%
Left home	32%
Cooked at a different time	24%
Pre-cooled the house	12%
Turned off pool pump	7%

Additionally, 52% of those contacts who were aware of events reported making changes in their day-to-day energy use as a result of RYU days and the information they received. Common changes reported included turning off lights (31%), adjusting air conditioner settings (23%), and turning off unused devices (20%).

Event Attitudes

Those contacts who had made an effort to reduce their energy use reported on their primary motivation to do so (Figure 5). Given three possible motivations, overall, respondent selections were relatively evenly distributed between earning a bill credit (38%), doing their part for San Diego (34%), and helping the environment (28%). Among the opt-in alert group, a majority (59%) reported that earning a bill credit was their primary motivation.

Figure 5: Primary Motivation to Reduce in Response to SDG&E's Request

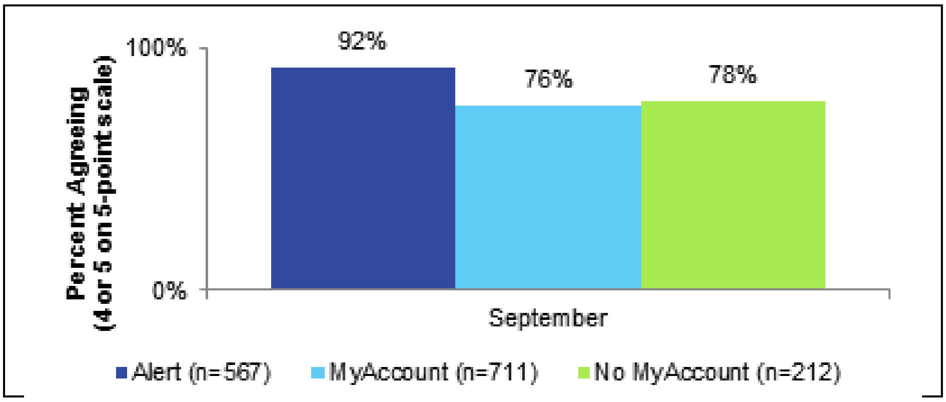


Those contacts who had not made an effort to reduce their energy use also commented on their reasons. Although many contacts did not answer the question, among those that did, the most common reasons for not making an effort to reduce energy use included reports that they were already conserving energy, or that it was too hot to participate that day.

In open-ended comments responding to the question of how SDG&E could make event days work better for customers, 16% of respondents provided comments about their efforts (or lack thereof) to reduce their energy use on event days. Most of these comments discussed the circumstances that limited customers' ability to respond to events. The most frequently mentioned topic was that the respondent already makes a daily effort to conserve energy use (63% of these respondents). One-third of these contacts (37%) reported that there was nothing they could do to reduce energy on event days. Other comments included that customers would try, within reason, to conserve (15%), that they made an effort, but received no credit (13%), that they found the campaign unfair to low energy users (8%), and that medical or other household issues limited their ability to conserve (7%). Just a few contacts (4%) reported that they did not want to participate.

Overall, contacts were satisfied with their experience of events and willing to participate in the future. While just half of contacts agreed that the value of the bill credit was reasonable, most of those contacted reported that they would be "very" or "somewhat" likely to participate in the future (Figure 6), and 93% of contacts said that they would be "somewhat" or "very" likely to sign up for notifications if it was required to receive a bill credit.

Figure 6: Willingness to Participate in Future Events[6]



6 Survey samples sizes for Figure 6:

July: Alert (n=198), MyAccount (n=97), No MyAccount (n=90);

August: Alert (n=154), MyAccount (n=69), No MyAccount (n=64); and

September: Alert (n=567), MyAccount (n=711), No MyAccount (n=212).

Curtailment Correlates

A key component of this evaluation was understanding the extent to which reported effort on event days was correlated with greater observed curtailment, and the factors that moderated the effect of reported effort on actual curtailment.

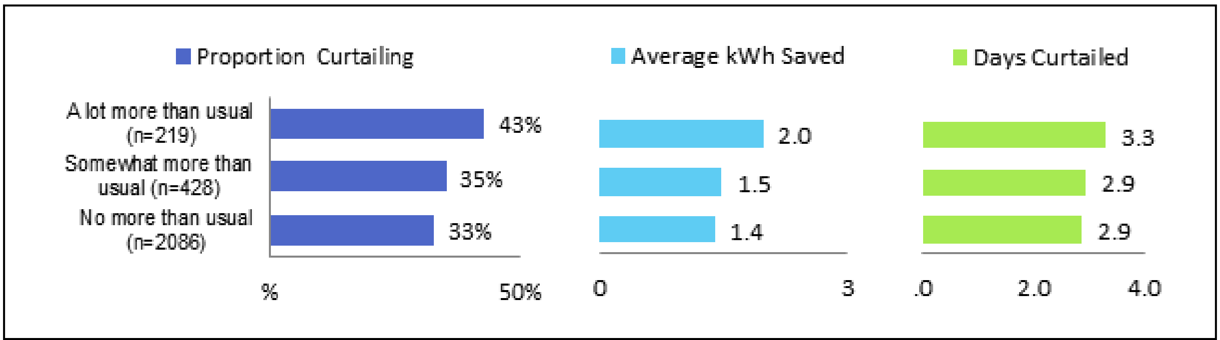
Although the bill credit was based on the number of kWh curtailed during the seven-hour event period, the research team hypothesized that demographic factors and external constraints -such as house size, use of air conditioning, number of occupants, or presence of small children in the home - likely drove a substantial portion of the magnitude of event-day savings for customers. To try to isolate the effects of self-reported behaviors on curtailment, the research team explored three separate measures of performance in this analysis:

- kWh savings (the kWh saved during an individual event),
- Binary savings (whether any kWh was saved during the individual event), and
- Curtailment consistency (the number of event days out of seven with measured curtailment.)

The first two measures of performance quantify performance on a particular event day, while the third quantifies performance across all PTR events.

A preliminary examination of the relationship between effort and curtailment suggested that reported effort was only moderately correlated with actual performance (Figure 7). One-third of those who reported making no more effort to save energy than usual (including those who were unaware of the event) had saved energy on the event day, compared with 43% of those who reported making a lot more effort than usual. These non-effort performers, combined with the presence of high effort non-performers (57%), suggest that a considerable proportion of event performance could have been due to chance: reflecting only random variations in residential energy use. Analysis of the August 14 event and survey data revealed similar patterns.

Figure 7: Proportion Curtailing, kWh Saved, and Days Curtailed by Reported Level of Effort



Analytical Approach

CART modeling was employed to better understand which demographic and behavioral factors best associate with customers' curtailment during PTR events. This exploratory analysis examines the relative predictive strength of independent variables relative to a dependent variable (in this case, event performance.)[7] That is, these models determine which demographic, attitudinal, or behavioral factors are most strongly related to event performance, and also give us a sense of how well these predictors explained event performance.

Twenty-one predictor variables were included in each model. Demographic factors included average kWh use, climate zone, home size, income, number of occupants, presence of children under 5 years old, presence of children under 18 years old, presence of seniors, home ownership, ethnicity, air

[7] See Therneau & Atkinson, 2012 "An Introduction to Recursive Partitioning Using the RPART Routines" at http://cran.r-project.org/web/packages/rpart/vignettes/longintro.pdf for a more complete discussion of CART models.

conditioning use, and pool ownership. Behavioral factors included alert opt-in, SDEC opt-in, online account signup, reported number of actions taken, self-reported level of effort, and logon to tracking website. In addition, awareness and attitudinal factors considered were awareness of event, awareness of concept, and motivation to curtail. All variables were self-reported except for average kWh use, alert and SDEC opt-in status, and My Account signup.

The CART analysis was conducted with 2,885 responses from a post-event survey, matched with performance data both for that specific event and across all events. The evaluation team used multiple regression to confirm the relationships identified in the CART models, both with the responses from the same event day, and on the responses from a separate post-event survey of a different event day. [4]

Curtailment Consistency Metric

A series of CART models were conducted with different transformations of the three outcome variables (Table 3 summarizes the results of the best CART model for each)).[8] The overall predictive power of the "binary savings" model was very low, with an R^2 indicating that the model explained just 3% of the variance in whether or not customers curtailed on September 15. In fact, all models for this outcome variable predicted savings would be less than chance. The overall predictive power of the total "kWh savings" model was moderate. This model explained 16% of the variance among those customers who saved at least 1 kWh on September 15.[9] The only two significant predictors in this model, though, were demographic predictors (average kWh use and AC use) rather than behavioral or attitudinal ones. That is, reported awareness of the event and reported actions to reduce energy use during the event were not significantly related to increased savings among those customers who were able to save at least 1 kWh. Finally, the "curtailment consistency" model had modest predictive power (explaining 9% of the variance in the number of days curtailed), but included significant behavioral, as well as demographic factors. Specifically, both opting-in for an alert and participating in the SDEC predicted a greater number of days with measured curtailment.

Table 3: September Event Regression Tree Explanatory Value

Dependent Variable	Model R^2 Value	Independent Variables in Best Model
Binary savings (saved any kWh during event)	0.03	N/A
kWh savings (among those who saved ≥1 kWh)	0.16	Average kWh use, AC
Curtailment consistency (number of days)	0.09	Average kWh use, Alert Opt-in, SDEC Opt-in

CART Results

Figure 8 shows the regression tree for the model predicting curtailment consistency (the number of days reduced, out of seven). Each rectangle, or node, is a variable where the tree splits. The labels below each node show the split points for the variable. Regression trees model the best "split" for continuous independent variables, such as average monthly kWh use. The circles are terminal leaves in the tree, the model's estimate for the number of days reduced by that subset of customers. Light colors indicate lower curtailment consistency, while dark colors indicate higher curtailment consistency.

The diagram below shows the best (black) and complete (gray) regression tree for curtailment consistency among the September 15 sample. Although these results do not conclusively indicate that the gray branches are meaningful predictors of curtailment consistency, they are included here because of the story they tell about the interaction between demographic and behavioral factors.

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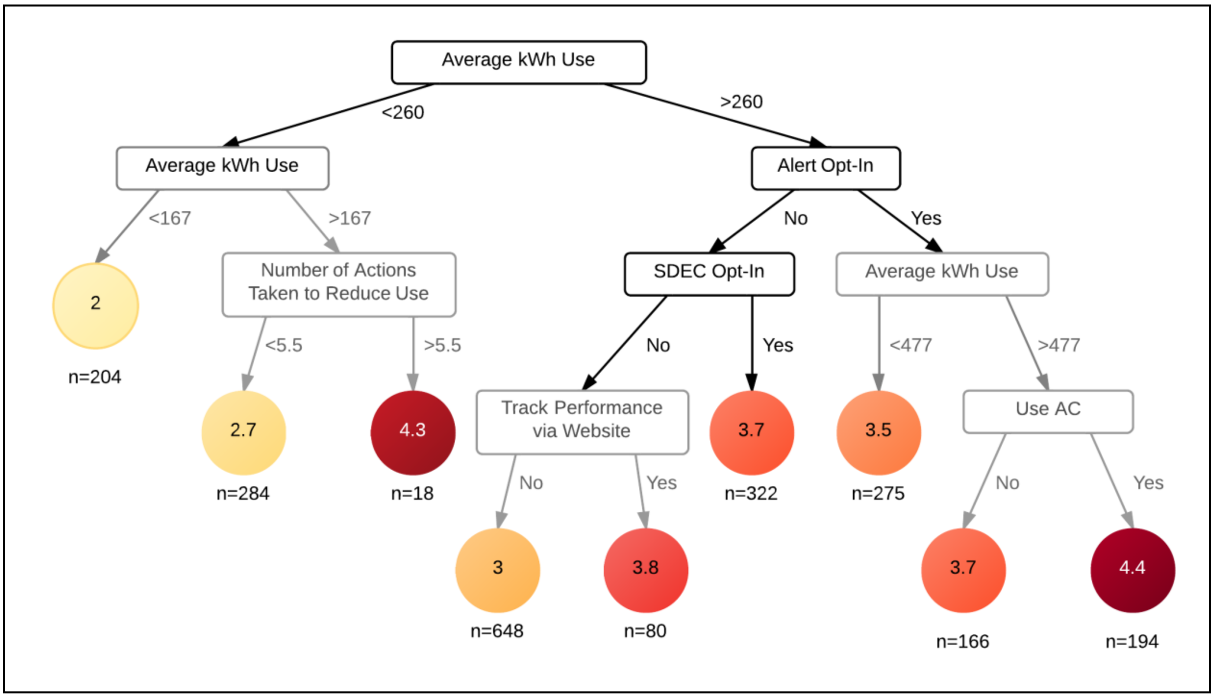
[8] The best model was determined by "pruning" the initial tree according to the 1-Standard Error rule, choosing the simplest tree where the risk is within one standard error of its achieved minimum.

[9] Because the kWh saved variable is highly skewed, we instead examined whether, among those contacts who had saved any energy during the event, behavior and attitudinal factors were related to the amount of savings.

Figure 8: Regression Tree (Predictors of Curtailment Consistency, Data: September 15 Sample)



Black nodes are part of best model. Gray nodes not part of the best model, but each increase R^2 by at least 0.005.

The CART analysis suggests several takeaways about curtailment consistency:

Low use customers may not be suited for this program. For customers using less than 260 kWh per month, opting-in to receive an alert or enrolling in the SDEC program does not significantly predict greater consistency of event performance. There is a small subset of customers (n=18) in our sample for who use between 167 and 260 kWh per month and who reduced their use an average of 4.3 out of 7 days, by trying very hard (that is, they reported performing at least 6 of the 10 actions we listed during the 9/15 event). Even among Alert opt-ins, those with energy use above 477 kWh per month, particularly those who used air conditioning, had higher average consistency than the others.

Voluntary engagement is important. Among those customers using more than 260 kWh a month, signing up to receive alerts or enrolling in the SDEC program does predict increased performance consistency, relative to others. Among those who did not opt-in, those that reported tracking their performance via the website also had more performing days than their non-tracking counterparts (an average of 3.8 of 7 versus 3 of 7 days).

Overall, this model suggests that engagement with RYU events played a role in how many days customers were able to curtail, but that the largest predictor of consistent curtailment is average monthly electricity use. Confirmatory regression largely confirmed these findings: both the effect of opting-in for an alert, and to some extent, the effect of event day effort, is dependent on overall kWh use. [4]

Conclusions and Recommendations

Based on the four waves of surveys and the CART analysis that augmented the research team's survey findings, several considerations emerged for future behavioral demand response programs, which are discussed below.

The PTR process evaluation identified several key decisions facing SDG&E and other utilities that might consider a territory-wide, behavior-based rate credit for voluntary demand response that result in measured curtailment. While respondents were generally satisfied with their experience and did not resent being asked to curtail their energy use during RYU days, comparing survey results with the energy consumption reduced relative to customer reference baseline revealed the limitations of assuming that reported awareness and action would correlate to measured curtailment. Based on these findings, we provide the following recommendations for behavior-based demand response programs:

Require an action to receive a bill credit. Opting-in for an alert was the most important behavioral factor affecting curtailment performance across multiple event days. Opting-in for an alert is important for two reasons. First, lack of awareness and information is a key barrier to participation, and opting-in for an alert virtually ensures event notification. Second, opting-in for an alert likely reflects increased overall engagement with SDG&E generally, and PTR specifically, because of the commitment represented in the simple action of registering for alerts.

Target recruitment: sectors are very hard to reach, and others can do little to participate. Event awareness among customers without MyAccount lags behind awareness among those with MyAccount. Television is an effective alert tool for a portion of these contacts, yet many of these customers prefer mail notification of events, indicating a lack of understanding about demand response, as well as a lack of engagement. Generally, low users (260 kWh a month and below) only receive incentives through extraordinary effort. Furthermore, some low users (both actual and perceived) feel disadvantaged by the program and want recognition for their daily efforts to conserve energy.

Align incentives with existing motivations. The per-kWh incentive used in the PTR program has both positives and negatives: some customers found the kWh feedback motivating, but for others, the incentive was not well-aligned with community or environmental motivations to participate, and this engendered frustration that the program is unfair to low energy users. In addition, the payment per event is generally small – less than a few dollars – and may focus participants too much on the specific payment associated with what might be extraordinary effort. Providing a seasonal incentive for everyone that curtails for a certain number of days, or to save a threshold level, could allow a larger one-time payment (such as $10). Providing an incentive for enrolling in voluntary alerts could also tap into the bill credit interest reported by the alert group, while also encouraging more widespread enrollment in alerts.

Develop a strategy for encouraging ongoing energy savings or encouraging more engagement with premise-level consumption. At least half of contacts who were aware of PTR events reported making day-to-day changes to reduce their energy use. Similarly, for a notable segment of customers, PTR created a desire for more information about their household's energy use. These may be opportunities for utilities to leverage demand response programs to increase participation in other programs, including detailed feedback strategies available through in-home displays or with enhanced websites.

Evaluation Lessons Learned

Matching survey results to impact data can help give a more complete picture of which customers are engaging with the program and the factors that are most correlated with successful curtailment. The CART model, in this case, was also a good analytical tool. From a methodological perspective, it helps isolate those variables that explained the most variance in curtailment consistency. From a practical perspective, it generates an easily-visualized segmentation of participants. The outcome of the CART model was more accessible and more actionable than a regression model, which would have revealed relationships between variables, but not cut points.

There are some practical considerations in implementing this approach in other evaluations. We found that memories of these demand response events faded quickly, and thus the post-event survey approach was useful in maximizing response accuracy. We also found that, while web surveys enable the large sample sizes that such data mining approaches require, using utility email addresses can introduce bias, particularly when email is the primary means of program alerts. From a process perspective, single demand-response events provide only a partial picture of how customers engage with events.

Finally, there are several cautions to using the CART methodology. Most fundamentally, CART requires very large sample sizes. CART models are optimized on a per-split basis, not on a model basis, so there is a risk of over-fitting. Multiple highly-correlated variables are unlikely to appear in the same model.

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The Demand Reduction Potential of Smart Appliances in U.S. Homes

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Abstract

The widespread deployment of demand response (DR)-enabled smart home appliances is expected to have significant reduction in the demand of electricity during peak hours. The work documented in this paper focuses on estimating the demand shift resulting from installation of DR-enabled appliances in the U.S. This estimation is based on analyzing the market for such DR-enabled smart appliances, using the number of appliances having replacement potential in the near future in addition to those installed in new homes. This estimate has been used to calculate total demand that can potentially be shifted by DR control in appliances and their sub components such as the refrigerator defrost cycle to identify power consumptions and savings resulting from interrupting and shifting their demand. In addition to major residential appliances, residential pool pumps are also included in this study, because their energy consumption profiles make them favorable for DR applications. Conclusions about the effectiveness of the smart appliances in reducing electrical demand have been drawn and a ranking of appliances in terms of their contribution to demand shift is presented. This research showed that DR-enabled water heaters result in the maximum demand shift; whereas dishwashers have the highest user elasticity and hence the highest potential for demand shifting through DR.

This work is part of a larger effort to develop novel home energy management concepts and technologies to reduce energy consumption and peak electricity demand through integrating renewables, storage technology, and changing homeowner behavior to manage energy by making more informed decisions about energy use.

Introduction

Research work in the modernization of the power grid has led to increased efforts in the design and manufacturing of residential smart appliances. These appliances include clothes washers and dryers, dishwashers, refrigerators, cooking ranges, and water heaters. They are referred to as “smart” because they include demand response (DR) capability, allowing them to respond to signals sent by an electric utility as part of a demand reduction program. Several institutions have reported a favorable market potential for smart appliances, stating that residential appliances have a high potential to be integrated into DR programs. The widespread deployment of DR-enabled home appliances is expected to have significant reduction in the demand of electricity during peak hours. Such programs have been developed by various utility companies based on electricity tariffs and are projected to result in cost savings in electric transmission and distribution (T&D) infrastructure or cost deferment in new T&D through the wide-scale deployment of such appliances.

The residential class in the U.S. represents the most untapped potential for DR programs [1]. While residential customers currently provide only roughly 17 percent of today’s demand response potential, in an achievable participation scenario, they could provide over 45 percent of the potential impacts [1]. In addition, in the U.S. household smart appliance market is projected to grow from $1.42b to $5.46b [2]. In terms of market share, it is very likely that all major home appliances will be "Smart Grid" ready within the next five years. For example, in 2009, Whirlpool announced that all of its electronically controlled appliances will be "Smart Grid" compatible by 2015 [3].

The work documented in this paper focuses on estimating the power demand shift resulting from the installation of DR-enabled appliances, calculated by analyzing the market potential for these appliances. Appliance operation is examined by considering their sub-systems individually to identify power consumptions and savings resulting from interrupting and shifting their demand. In the market analysis study documented in this paper, data from the U.S. Energy Information Administration's (EIA) Residential Energy Consumption Survey (RECS)[4] and National Association of Home Builders (NAHB)[5] databases are used to examine the expected life of an appliance and the number of appliances installed in homes constructed in 10 year intervals after 1940. These data were used as criteria to estimate the number of appliances that have potential to be replaced with smart appliances in the near future. The demand shift resulting from deployment of smart appliances was then estimated using total power consumption of each appliance. Other factors considered in the demand reduction potential were user elasticity, delay acceptance, duty cycle, and the total power used in one appliance cycle. These analyses allowed the authors to draw conclusions about the effectiveness of the smart appliances in reducing electrical demand and rank appliances based on their potential for DR-enabled operation. Results show that DR-enabled water heaters result in the maximum demand shift because of their high energy usage; whereas dishwashers result in high load shift because of the high user elasticity associated with them.

The work documented in this paper is part of an overall objective to create a system that adjusts its recommendations to homeowners' expressed preferences for convenience of service (CoS), gathered at system configuration time. Also, the system monitors energy use behaviors under different activity or occupancy conditions and suggests adjustments to appliance use. The system monitors inputs from multiple sources to create a hypothesis of the current state and to build patterns of energy use in the home over time. These patterns enable the determination of homeowner CoS preferences and the generation of recommendations. The monitored inputs include occupancy sensors, indications from the security system, positions of light switches, hot water consumption, appliance activity (e.g., the operation of the dishwasher), and time of day. The system can then adjust the time of operation for these appliances to be recommended to the user to match the actual schedule followed by the user, rather than a pre-programmed schedule that ignores user preference. The value of this system is expected to increase as more context information becomes available, as the system learns more about occupant behavior and as more connected appliances are installed.

The work reported in this paper included the analysis of home appliance demand profiles and number of household appliances from publically available databases to recommend better modes of operations for DR-enabled appliances. In the following sections a background of existing work in the domain of evaluating DR-enabled residential appliances is provided followed by a description of the market analysis method and results. Residential-based data sources and resources that were found to be most relevant are also documented.

Background

Various methods have been employed to determine the feasibility, benefits and impact of implementing DR features in residential appliances. In these methods, the benefits considered are distinct from those arising as a result of traditional machine enhancements that enable operational efficiencies; rather, these benefits are focused on the demand shift potential made possible by DR-enabled residential appliances. Residential appliances investigated in most studies include heating ventilation and air conditioning (HVAC) systems, electric water heaters (EWH), clothes dryers and washers, dishwashers, refrigerators, freezers, miscellaneous light and plug loads, and cooktop range and ovens. There is limited research addressing DR-enabled pool pumps. Although very small in number, given their energy consumption profiles, pool pumps are favorable for DR applications

Existing research has estimated the peak reduction of DR appliances as well as the monetary value brought through DR. The existing works may be categorized as:

- Those that focus on estimating the peak energy demand shifting potential of DR appliances through appliance models in simulation environments (typically using GridLAB-D[1]),
- Those that examine the feasibility of DR appliances to function as spinning reserves and ancillary services[2] benefiting the electric utility, and
- Those that estimate the market for new appliances with DR capabilities.

These are explained further in the sections below. The third category of estimating the potential for demand shifting through DR by estimating the market is the focus of this paper.

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[1] GridLAB-D is an open-source, state-of-the-art software designed at PNNL for the Department of Energy's Office of Electricity Delivery and Energy Reliability to simulate the complexities of the smart grid from the substation down to the end-use load. http://www.gridlabd.org/

[2] Ancillary services refer to balancing services in an electric utility supply system that help overcome fluctuations and maintain supply/demand balance. For example, services needed to correct for fluctuations in the minute to minute system load and generator output are referred to as "regulation" and "load following" services [30]. Balancing services over longer time frames include demand response programs.

Model-Based Evaluations

In works that examine the potential technical benefit, that is, peak energy reduction (or demand shifting) potential of DR appliances through simulation environments, several efforts have focused on modeling techniques for DR appliances. In [6], the authors developed individual DR-enabled models of residential HVAC, clothes dryer, and electrical vehicle loads. The authors claimed that these models can be used by others for DR studies at the household and the distribution circuit levels, given a set of customer behaviors and signals from a utility as inputs to the model.

In [7], the authors developed multi-state appliance models of GE Appliances' DR-enabled appliances that are used to represent power demand and energy consumption as well as the DR control systems developed by GE Appliances. A key conclusion of this work is that while the response of a single appliance in a home provides relatively small benefits compared to an HVAC system, given the greater number of appliances in the home, the aggregate behavior of a suite of DR-enabled appliances is significant. Through a simulation environment the authors concluded that even at low market penetration levels of 5% and 25% of General Electric DR-enabled appliances, the appliances alone are able to provide peak reduction capabilities of 1-2% and 4-5%, respectively.

In addition to creating models, several studies have used models in simulation environments to examine DR control strategies. For example, in [8], the authors examined DR strategies using a simulation of over 100 electric water heaters and provide guidelines for effective implementation of DR in these appliances. These guidelines include changing the temperature setpoint in the electric water heater to reduce electric demand (i.e. lowering the water temperature setpoint) or absorb excess capacity by increasing the water temperature setpoint in the tank and using a mixing valve to deliver water to the faucet at the original setpoint temperature. In [9], the authors examined the impact of residential-level DR on the operation of the power grid using detailed end-use load models. The authors implemented an active DR strategy, including active controllers, and examined 3 cases—no price signal, one hour price signal, and 15 minute price signal—to evaluate the impacts of DR on the distribution system operations. The authors demonstrated that a 15 minute price signal results in numerous but less severe demand peaks compared to one hour price signals. In addition, they demonstrated the level of modeling detail required for such studies.

In [10], the authors analyzed the effect of residential DR on the power grid with a double auction market where both suppliers and end-use loads simultaneously submit bids for price and quantity into a single market. The authors demonstrated the need for analytical models at multiple levels within the simulation through a demand response program utilizing distributed and centralized control. However, in [11], the authors stated that advanced DR-enabled simulation models of appliances are limited and do not adequately estimate the load shifting potential of DR-enabled appliances. The authors use a screening analysis of technologies and conclude that, while DR can be used to mitigate generation intermittency, the maximum potential for demand shifting, which does not harm consumers, may be significantly less than expected.

Utility Company-Based Smart Appliance Programs and Evaluations

In [12], the authors document a study to evaluate the benefits of DR-enabled appliances with respect to peak-demand reduction and spinning reserves, and evaluate DR-enabled appliances from a utility/grid perspective. The authors report the production cost savings to utilities and the extent to which DR-enabled appliances can provide ancillary services to facilitate greater penetration of renewable generation sources, specifically, wind and solar. The methodology adopted is based on expected smart appliance penetration and usage rates, daily usage patterns, and definitions of peak and off-peak periods. In establishing the monetary value of benefits, historical wholesale market clearing prices are drawn from various electric power markets including NYISO [13], CAISO [14], PJM [15], and ERCOT [16]. In [7], the authors look at historical market data to estimate the savings available to consumers and/or utilities by using DR capabilities in residential appliances. The authors examine the effects on wholesale energy cost and possible additional revenue available by consumer participation in frequency regulation and spinning reserve markets through the use of DR-enabled appliances.

Utility companies operate programs to reduce energy consumption during peak times by controlling cycling interval of some home appliances. For example, "EnergyWise Home" program offered by Progress Energy works across the community to lower energy usage during peak periods. Customer participation is voluntary and includes the control switch/receiver. In a year, the customer can receive up to $147 in bill credit. Table lists a sample set of utility companies in the U.S. that have residential demand management programs. Most of these are focused on AC and water heater cycling.

Table 1. Utility Companies With Community-Scale Home Energy Management Programs

Company	Name of the Program	Location	Cycling Interval/Control periods	Savings	Appliance/ equipment controlled
Progress Energy[18]	EnergyWise	Florida	Not identified	Up to $147 credit (annual)	Water heater, pool pump, HVAC
Alliant Energy [19]	Appliance Cycling	Iowa and Wisconsin	Every 15 min (1 pm -7pm)	$45 credit (annual)	HVAC and water heater
DTE Energy [20]	CoolCurrents	Ohio	Not identified	Up to 20% annual saving on AC bill (there is a $1.95 monthly charge)	HVAC
Price Electric Cooperative[21]	Water heater thermal storage program	Wisconsin	4 hour control program	$50–$350 rebates depending on the size of water heater	Water heater
Dairyland Power Cooperative/Jackson Electric Cooperative [22,23]	Water heater program	Wisconsin	Not identified/ limited to 6 hours per day	$3 credit (monthly)	Water heater

Market Study-Based Evaluations

The current state of the smart appliance market is addressed in a report by Pike Research [24]. Here, the authors include an analysis of barriers and drivers, enabling technologies, regulatory factors, and key industry players. There are a limited number of studies focusing on deployment of DR-enabled appliances and evaluation of their operation in a population of normally functioning homes. Under the Pacific Northwest National Laboratory (PNNL) and Bonneville Power Administration (BPA) sponsored Olympic Peninsula Project approximately 100 homes were equipped with thermostats, electric water heaters, and clothes dryers that would react to pricing signals (both real-time and time-of-use) [25]. The participants were on either a time-of-use (TOU) or real-time pricing (RTP) tariff and thus were able to take advantage of the demand reduction. Over the course of a year, average peak reductions of 1.0–1.5 kW per household were observed, with cost savings of up to 30% based on TOU pricing and 27% based on RTP [25].

Market Size Estimation

In this section, the potential market for smart appliances in the near future in the U.S. is estimated. This estimation includes the number of appliances that are reaching the end of their life expectancy and are ready for replacement in the near future plus the forecast of appliances that will be installed in new residential constructions. Data were extracted accordingly from RECS [4] and the U.S. Census Bureau [26]. RECS is a national sample survey that includes energy-related data for different housing type units. The survey data included is from 2009, but the total and average consumption data are from 2005 databases. EIA states on its website that “RECS consumption and expenditures data for 2009 are currently being collected and processed and anticipated the first release of these data in early 2012 [4], however, these were not available when this research was carried out. 2009 data were collected from 12,083 households selected randomly (using a complex multistage, area-probability sample design). This sample represents 113.6 million U.S. households. The U.S. Census Bureau statistical estimate for all occupied housing units in 2009 is derived from their American Community Survey (ACS) [26]. EIA estimates energy consumption and end uses in the U.S. by collecting energy characteristics on the housing unit, usage patterns, and household demographics. Energy costs and usage for heating, cooling, appliances, and other end uses are then estimated using data from energy suppliers to these homes.

This paper assumes that all consumers will replace their old electric appliances reaching the end of their useful life with a smart one. For such assumption to be valid, we recognize that the consumer will only buy a high price smart appliance if they can see some monetary value over time or other benefits (e.g. environmental benefits). Household income will likely play a major role in a consumer's decision to buy a smart appliance as opposed to a conventional one because of the higher cost of DR-enabled appliances. However, the authors assume there will be enough incentives from the government or power utilities to eventually encourage all consumers to buy smart appliances. Such incentives or grants are required to support DR capabilities of the Smart Grid (i.e., time of use pricing) which cannot be realized without smart appliances in place.

Life Expectancy of Appliances

Home appliances have a limited life expectancy. To estimate the market, the first step is to determine the useful life of appliances. The National Association of Homebuilders (NAHB) and Home Inspectors (e.g., ATD Home Inspection) have undertaken studies to determine the approximate life expectancy of majority of household appliances. Table 2 shows a summary of NAHB's study of life expectancy of home appliances compared to minimum and maximum useful life of appliances reported from other studies.

Table 2. Life Expectancy of Home Appliances

Appliances	Expected number of years reported by NAHB	Average number of years from other studies
Pool pump	Not available	5–12
Range (electric)	13	8–15
Refrigerator	13	8–14
Clothes washer	10	5–15
Clothes dryer (electric)	13	8–14
Dishwasher	9	7–12
Water heater (electric)	11	10–11

Based on the data tabulated in Table 2, in the U.S., a good assumption is that clothes washers, dishwashers, and water heaters older than 10 years of age and refrigerators, ranges, and clothes dryers older than 15 years old will be replaced in the near future. The potential market size for smart appliances was estimated based on this assumption.

Number of Appliances Having High Replacement Potential

Analyzing data from RECS reveals the number of appliances reaching the end of their life expectancy. These data are plotted in Figure 1 based on year of home construction and also tabulated in Table 3. There are 12.4 million refrigerators, 7.1 million second refrigerators[3], 25.3 million clothes washers, 10.7 million clothes dryers, 19.4 million dishwashers and 42.1 million water heaters [4]. Out of 113.6 million water heaters installed, 43.7 million (39%) are electric. Therefore, out of 42.1 million water heaters that are older than 10 years of age, about 16-17 million are electric and ready for replacement. RECS data also shows that about 79.5% of clothes dryers currently installed are electric. Therefore, 8.5 million of 10.7 million clothes dryers that are reaching their maximum life span are electric. Unfortunately, RECS has no data on age of electric ranges. Total number of electric ranges in 2009 was reported as 61.9 million, which is about 60% of total electric ranges. The trend for potential appliance replacement in the past 60 years is shown in Figure 1. This trend shows that on average about 11% of those appliances with life expectancy within 15 years have had replacement potential in the past six decades. These figures are used to estimate market size for ranges that are ready to be replaced. Because a range life expectancy is around 15 years, it is estimated that about

[3] About 22% of total homes in the U.S. have second refrigerator [4]. However, these units are not expected to be replaced with smart ones the near future, but authors have considered these in the analysis to be consistent with the remaining data.

11 percent of them have replacement potential. Pool pumps and motors have an average life span of about ten years and there are about 120,000 units ready for replacement each year [27].

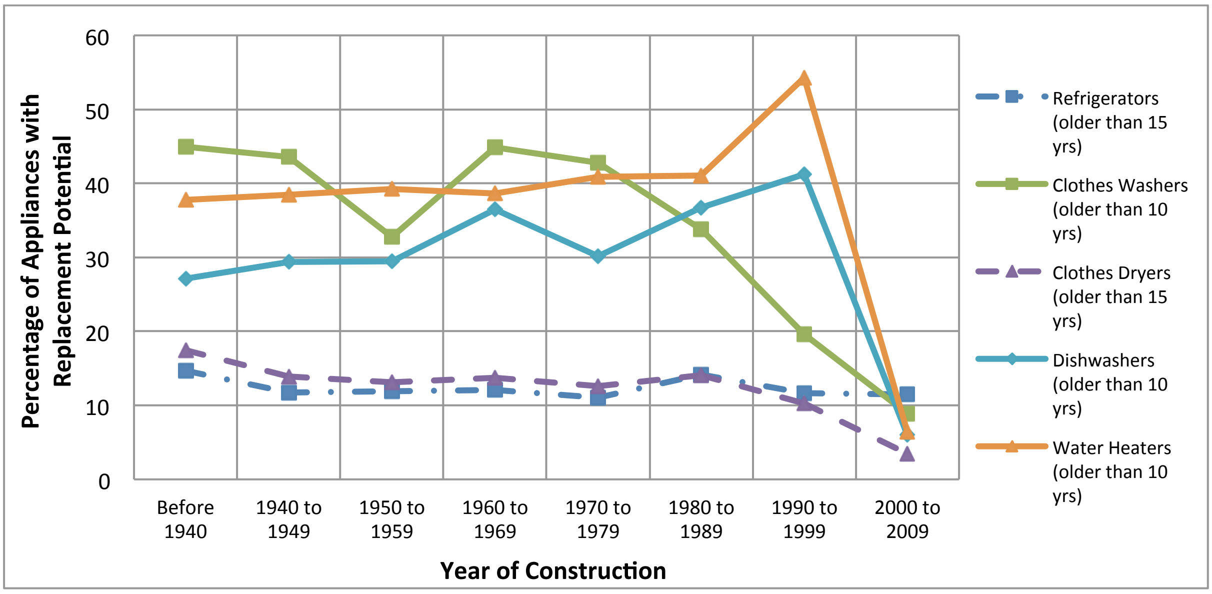

Figure 1. Replacement Trend of Appliances Based on Year of Construction of Homes

Number of Appliances Installed in New Homes

According to the U.S. Census Bureau [26], there were 306,000 new constructed homes sold in 2011, all of which likely needed a new refrigerator, clothes washer, and dishwasher. Analyzing RECS [4] database shows that currently 79.5% of clothes dryers and 39% of water heaters installed are electric. Therefore, it is assumed that 79.5% of new homes built would have a new electric clothes dryer and 39% would install a new electric water heater. Not all homes have pools and pool pumps. In [27], it is reported that there are about 22,700 new sales of pool pumps each year. The total market size for these appliances is estimated by adding the number of units that have replacement potential with the new units added each year. Results are tabulated in Table 3 and illustrated in Figure 2.

Table 3. Estimate of Market Size of Appliances and Pool Pumps

Appliance/Equipment	**Units Ready for Replacement**	**New Units**	**Total Units (in 2009)**
Refrigerator	12.4 million (11% of total)	306,000	12,706,000
Second refrigerator	7.1 million (27% of total)	70,035[4]	7,170,035
Range	6.8 million (11% of total)	183,600	6,983,600
Clothes washer	25.3 million (27% of total)	306,000	25,606,000
Clothes dryer	8.5 million (11% of total)	243,270	8,743,270
Dishwasher	19.4 million (28% of total)	306,000	19,706,000
Electric water heater	16.25 million (37% of total)	118,129	16,368,129
Pool pump	120,000	22,700	142,712

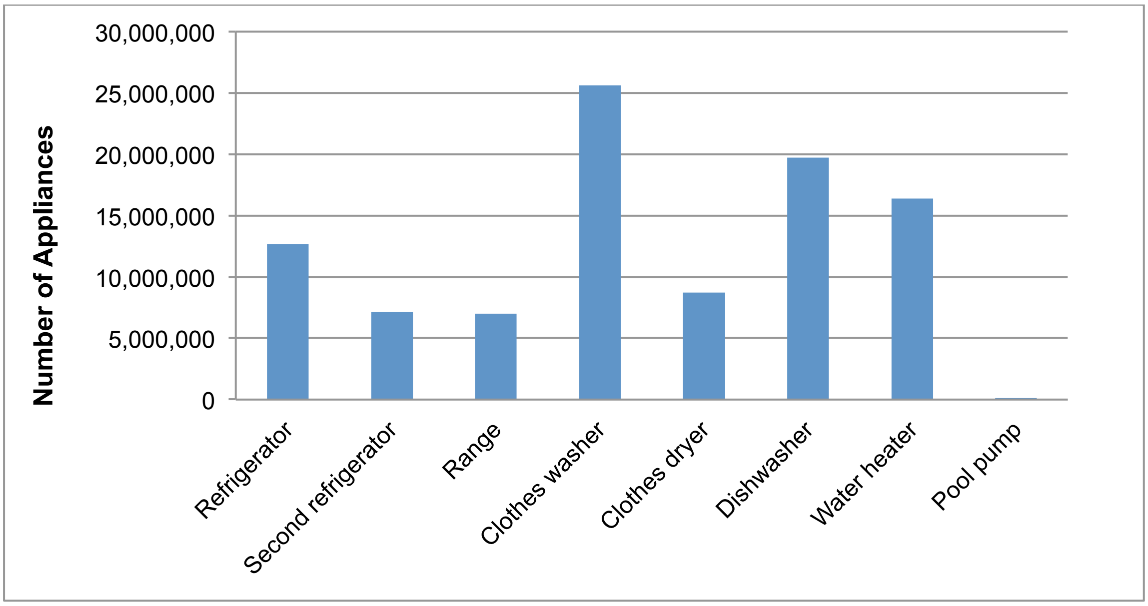

Figure 2. Estimate of Number of Appliances with Replacement Potential.

Demand Reduction Estimation

An estimation of the minimum and maximum amount of power that can be shifted in one cycle by a "typical" smart appliance is shown in Table 4 and plotted in Figure 3. The calculation is based on multiplying the estimated market size for smart appliances in the entire country by the demand response potential (i.e. the megawatts of power that can be shifted). These results are based on typical wattage of appliances reported by [28] as well as the estimation of market size given in Table 4 with the assumption that all appliances estimated in the market size analysis will be replaced with smart appliances. The results are not limited and do not consider only the portion of the country that has smart grid.

Based on results shown in Table 4, water heaters have the greatest potential for reducing demand during peak electrical demand. This is corroborated by other studies [17], which reveal similar results. Furthermore, these results are in line with DOE's residential water heater load control and electric thermal storage programs [29]. Programs shown previously in Table 1 support this finding as well; they show that utility companies have already started reducing electrical demand during peak hours by controlling cycling interval of water heaters. Many of these took place in response to the U.S. DOE's electric thermal storage program [29].

Table 4. Estimate Of Total Demand Shift by Smart Appliances

Appliance		Minimum Wattage	Maximum Wattage	Estimate of Smart Units (Based on RECS 2009)	Estimate of Minimum Total Demand Shifted [MW]	Estimate of Maximum Total Demand Shifted [MW]
Pool Pump		250	2000	142,712	36	285
Refrigerator	Defrost	400	400	12,706,000	5,082	5,082
	Compressor	450	700	12,706,000	5,718	8,894
Clothes Dryer	Entire device	1800	5000	8,743,270	15,738	43,716
	Heater off	1800	1800	8,743,270	15,738	15,738
Clothes Washer		350	500	25,606,000	8,962	12,803
Range	Oven	500	2500	6,983,600	3,492	17,459
	Cooktop	1200	2500	6,983,600	8,380	17,459
Dishwasher	Entirely	1200	2400	19,706,000	23,647	47,294
Water Heater		4500	5500	16,368,129	73,657	90,025

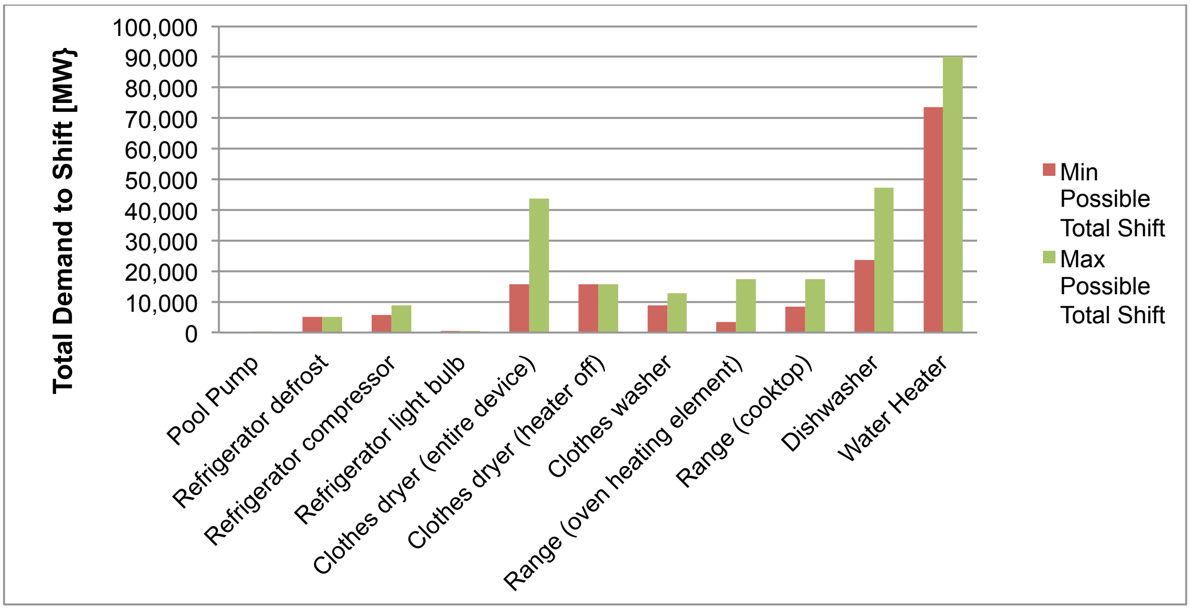

Figure 3. Minimum and Maximum Appliance Demand Shift Possible for Residential Appliances and Pool Pumps

Figure 3 also shows that after water heaters, smart dishwashers are second in the amount of demand shift. In addition to this observation, a study by PNNL [17] shows 90% of participants are willing (i.e., are elastic) to shift their dishwasher cycle to off-peak hours. Based on Figure 3, pool pumps have a low total potential for demand shifting because of their low numbers across the nation. However, the potential for demand shifting from on-peak to off peak for those residences that have pool pumps is approximately 2kW. Therefore, DR-enabled operation can be an advantage in controlling pool pumps.

Furthermore, the load shape of the dishwasher (Figure 4) indicates a potential for DR-enabled operation because there are several 'control' states (before wash cycle, before rinse cycle and before heated dry cycle) that may allow DR price signals to pause the dishwasher cycle, and then move to the next state when there is a lower price signal. Load models of other appliances indicate that the cooking range and clothes dryer do not have these 'control' states. However, clothes washers do have 'control' states before wash, rinse, and spin cycles, but pausing the operation between these cycles could harm wet clothes.

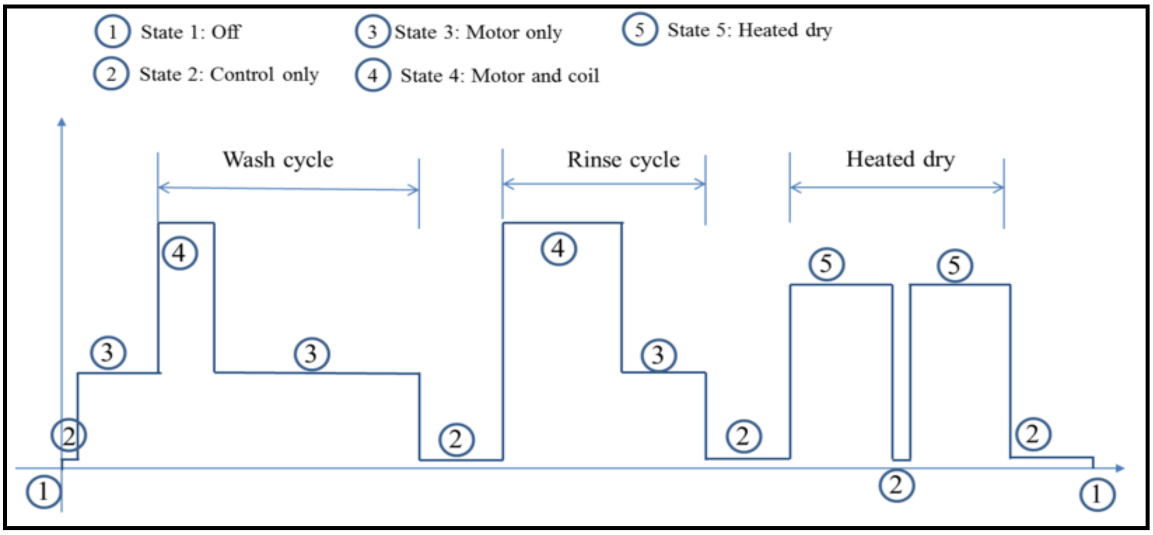

Figure 4. Multi-State Load Model of a Dishwasher Developed in GridLAB-D. These States are Determined Based on Level of Power Demand. *Source:* http://www.gridlabd.org/

Results and Discussion

The main objective of this paper was to analyze and estimate the market and identify DR-enabled appliances (i.e. smart appliances) that result in maximum load shift. The data presented show widespread deployment of demand response enabled home appliances (e.g., smart appliances) could have potential significant reduction in the demand of electricity during peak hours. This analysis is based on estimates of future market size, total power that can be shifted during peak electrical demand hours, and technical potential of appliances to respond to price signals. Conclusions about the effectiveness of DR-enabled appliances in reducing electrical demand have been drawn and a ranking of appliances is presented in Table 5. Further work may be required to account for the rebound effect of appliances coming out of their curtailment states during high demand periods.

Table 5. Rank Order of Appliances Based on Maximum Potential for DR-Enabled Operation

Rank	Appliance	Summary of reasons
1	Water heater	Ubiquitous (everyone has one) High power use Maximum load shift of all appliances High user elasticity Demand shift can be undertaken with minimal capital cost (investment by the utility) and little impact on residents given the size of the water heater (thermal capacity) and time duration of the shift.
2	Dishwasher	Significant penetration of appliances in residences and therefore a high potential for load shifting High user elasticity Load shape allows cycle interruption and pausing to shift load May provide additional savings due to shift in electric water heater demand
3	Pool pump	High power use/unit, therefore potential for large demand shifting High user elasticity Low numbers across the nation
4	Clothes dryer	Moderate user elasticity High power use
5	Clothes washer	Moderate user elasticity Low power use May provide additional savings due to shift in electric water heater demand
6	Refrigerator	High user elasticity Relatively low power use
7	Cooking Range	Low user elasticity Moderate power use

Conclusions

The work documented in this paper examines the market for DR-enabled appliances and the potential for load shifting of DR appliances across the U.S. The numerical values in this paper are from publically available databases based on consumer surveys that are periodically updated. Therefore, the purpose of this paper is not to provide absolute market analysis numbers, but instead a demonstration of a method, factors to be considered and level of detail needed to analyze the market potential for DR-enabled appliances.

This paper presents scenarios based on technical potential. However the market study method reported in this paper does not address potential problems in implementing DR programs such as the rebound effect and coincident load shifting as described in [31]. For example, in the case of rebound effect, if all appliances start operating simultaneously at the termination of a DR period, a peak in electric demand will occur. It is necessary to understand and account for this phenomenon in DR study.

In addition, to determine 'true' impact DR programs, the behavior and attitude of the consumers is critical. The percentages of consumers who may override the DR signal cause difficulty in predicting the aggregate response of a large number of residences and thus additional research is needed to better understand consumer behavior. It is also critical to research the number of consumers who would choose to purchase a smart appliance over another without DR capability, and at what price point for the smart appliance do consumers make these choices. Lastly, it is important to understand the monetary value (if any) required for consumers to engage in DR programs beyond the limited data from the current programs involving primarily water heaters.

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Review of load research studies applied to the Portuguese household sector

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Abstract

In order to allow decision makers to select local, regional or national end-use energy efficiency policies it is necessary to assess the technical, economic, environmental and societal effect of replacing a given equipment or technology, or of adopting a given measure.

The deployment of Demand-Response programs and the recent trend towards combining the use of smart meters requires assessing their possible aggregated impact and for that purpose, the knowledge of the household consumption pattern and its composition in terms of the individual end-uses is fundamental.

This paper intends to review the most recent load research studies in the household sector in Portugal, focusing on individual end-uses and discussing their possible contribution towards the development of a methodology to assess the impacts of demand-response through automated control of residential appliances.

The common strategies to load modeling are normally based on top-down or bottom-up approaches, the first kind trying to derive load models from statistical data and the second kind building an aggregated model from engineering models of end-uses. These methodologies can be improved by the growing availability of data from smart-grids and smart-meters, thus taking advantage of these new types of data, as well as reducing costs associated with energy modeling, avoiding the complexity of such models and reducing the time required to perform these simulations.

A simple evaluation procedure was also developed to compare load profiles obtained for the residential sector by different reference studies that provide load diagrams, including reference load profiles.

Load Research Review

Similarly to what happened in other European countries, several studies regarding electrical energy use (especially consumption) have been developed in the past years giving a special attention to the Portuguese household sector. This attention is explainable due to the overall and growing importance of electrical energy consumption in this sector and in the total energy consumption of the country which accounts for a total of 3.932.010 households (3.773 .956 in Continental Portugal, 77.222 in the Azores Region and 80.832 in the Archipelago of Madeira) [1]. Another reason for the existence of these studies has to do with the alleged homogeneity of this sector, in terms of appliances or equipment, energy usage patterns and energy behaviors, which allowed the development of typical load profiles that intend to represent the energy consumption in households. According to a recent study [1], electricity in Portugal arises as the main source of energy used in households with 42.6% share, clearly surpassing the 15.8% share obtained in 1989 and 27.5% in 1996.

The popularity of equipment/appliances that use electric energy increased significantly, which contributed to the growing importance of the use of this type of energy in the household sector and motivated researchers to develop studies on the electrical energy usage in dwellings. This work will focus in reviewing the work that has been done for this Portuguese portrayal in the last decade.

The contribution for the assessment can be divided in four major branches, namely, monitoring studies, statistical studies and surveys, behavioral studies and also the current regulatory framework regarding the measurement, reading and electrical energy data availability in Portugal.

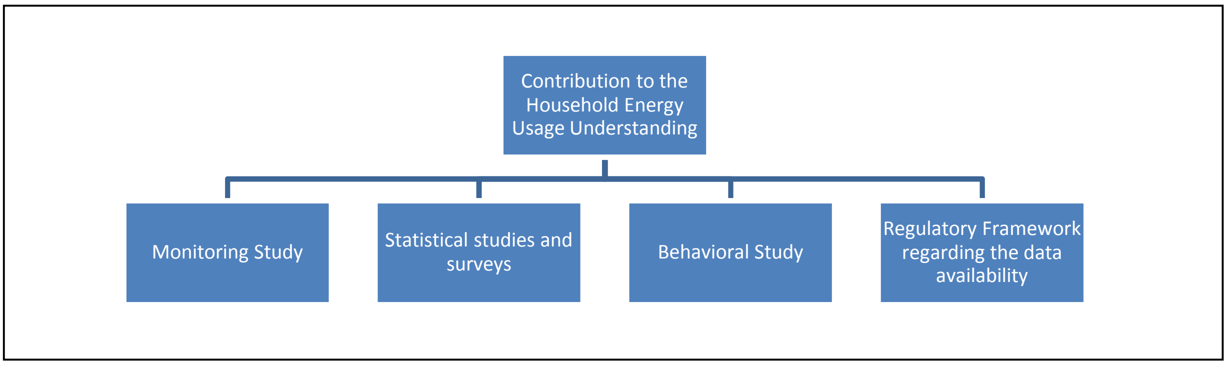


Figure 1 - Contribution to the household energy usage understanding according to the authors vision.

Monitoring studies

The first branch refers to the monitoring studies that have been made, with European and/or National public and private funding. These studies generally intend to identify Demand Side Management (DSM) actions and measures in order to encourage the end-user to be more energy efficient. These studies are also a good support for the evaluation of Demand Response (DR) programs which are designed to encourage end-users to make short-term reductions in energy demand in response to a price signal from the electricity hourly market, or a trigger initiated by the electricity grid operator. However, for the studies presented, only in [2] is considered the use of DR.

The EURECO project [3] was one of the first joint European projects to describe the state and structure of the specific electricity end-uses in the residential sector of Denmark, Greece, Italy and Portugal. This project intended in a first stage to confirm the results of the ECODROME project [4] regarding DSM actions (especially in lighting) that were evaluated in France. A more simple, cheaper methodology was also attempted that allowed the project to be replicated in those four countries also taking into account the imperatives of the Commission of the European Communities. The second purpose of ECODROME was to discover new trends, or consumptions that are still not accurately defined or comprehended, which could represent an important share of total consumption in the near future, e.g. standby consumption. The need to evaluate standby consumption came also from ECODROME [4] where a standby power of 117 W in a low income family apartment, which consumed 1,025 kWh/year in standby mode. With the conclusion of the EURECO project [3] a characterization of electricity end-uses was provided in normal operation and in standby mode, and the potential electricity savings of DSM actions was assessed.

The Ecofamilias study [5] was a Portuguese project that consisted in evaluating energy consumption through the monitoring of 30 Portuguese families (equipment consumption and temperature/humidity of dwellings) and implement measures to reduce consumption. The main conclusion of this study regarding energy savings was the replacement of incandescent lamps by compact fluorescent lamps, the elimination of power-off and stand-by consumption and the economic advantage for families for the adoption of a bi-hourly tariff instead of a simple tariff.

The REMODECE monitoring project [6] was a European partnership involving Belgium, Bulgarian, Czech Republic, Denmark, France, Germany, Greece, Hungary, Italy, Portugal and Romania. This study intended to understand better the electricity energy use in households, consumer lifestyles and comfort levels, taking into account the 2% yearly increase of electrical energy consumption in the EU-25 household sector that prevailed at the time. The study allowed an estimation of the average electricity consumption per household , excluding electric space heating and water heating, of 2.700 kWh and also a segregation of electricity end-uses according to the following percentages (Lighting 17%, refrigerator 25%, washing & drying 16%, office equipment 10%, entertainment 9%, air conditioning 10%, cooking 9% and others 4%). These percentages were drawn from the average daily load profiles.

The last monitoring study referenced is the Selina project [7], which focused exclusively on standby and off-mode energy losses in new appliances measured in shops. One of the findings of the project was that currently there is a large share of equipment in shops that do not respect the current legislation [8] regarding the consumption (power) in off mode, in standby for reactivation only and in standby for information and status display. The Selina project considered that the monitored values are similar to others from other regions of the world reflecting the global nature of the world market of electrical and electronic appliances. The result of the retailer's survey shows that the most used selling arguments are the appliance functionalities and price instead of the energy efficiency. Retailers also admitted that sometimes they advise products that are not the most efficient in order to avoid stock problems. The Selina project recommendations include the need for information programs, financial and fiscal incentives, energy labeling, minimum efficiency standards, advertising standby and off mode consumption in labeling.

The knowledge and experience provided by these studies allowed researchers to better understand electrical energy usage in households and to evolve research from a particular country case study [4] to a European study extended to 11 countries [6]. This is possibly because the appliances (and their deployment) in this geographical location are relatively similar, allowing the transfer or use of a common methodology for the study of load research studies. This similarity also provides the possibility of defining policies (DSM and DR) that can be deployed/implemented at an European level and subsequently verified [7].

Statistical studies and surveys

The second branch comprises statistical studies and surveys. These studies, especially the surveys, are very helpful to illustrate the current household sector in terms of housing, the type of energy sources used and present end-uses.

The study with reference [9] makes use of data from monitoring studies, but especially statistical information to define a set of policies regarding two types of DSM actions. The first action intends to reduce consumptions by using more efficient equipment and also recommending more rational use of the equipment/appliances (not quantified). The second DSM measure consisted of shifting consumption from peak hours (peak and partial peak) to off peak hours (off peak and super off peak), especially of clothes and dish washers. One of the project outputs was the estimation of the structure of the load diagram for the residential sector segregated by major end-uses.

From the diagram of [9] it is possible to verify that three specific uses of electricity (lighting, audiovisual equipment and cold) represent more than a third of the total evening peak demand. The project updated the percentages of energy end-use percentages.

The Portuguese energy agency ADENE [10] performed a study to analyze the energy usage in residential buildings in Portugal which assessed energy reduction and growth rates in relation to feasibility and cost, thus evaluating the most beneficial options (within the chosen criteria) to be adopted in the residential sector.

The recommendations of this study point to the need of awareness raising campaigns, of having segmented financial schemes (according to consumers income), of supporting community based projects in order to raise awareness, the advantages of using solar thermal collectors and also of training the public to measure the energy usage. The average Portuguese consumer does not know the amount of energy he/she consumes.

The official survey [1] intended to provide an up-to-date knowledge of the energy usage in the household sector for the different energy sources segregated by end-use. The total energy consumption for the household sector was estimated at 5,902,024 toe in 2010 (being 49.4% consumed in the household and 50.6% in individual transportation). In 2010 electricity was the main source of energy used (42.6%). In terms of segregated consumption by living quarters, kitchen 39%, water heating 23%, heating the household 21%, other electrical appliances 11% and lighting 5%.

Behavioral studies

The third branch portraits studies regarding the study of behaviors. According to Lopes et al. [11], energy behaviors represent a significant untapped potential for the increase of end-use energy efficiency, being usually neglected although it is as high as that of technological solutions.

In Portugal the only use of time study was published in [12]. Usually these studies are a possible contribution, e.g., for building bottom-up model [13] [14] using people routines under statistical elements to simulate behaviors and therefore estimate energy usage. According to the findings of this study [12] the way people use their time strongly depends of gender, if people are employed, however, it is more probable for women to keep the house and tend for children. Women spend also, an average of one hour less than men in paid work, but on the other hand, women spend 4.07 hours in housework for an average of 1.30 hours for men. The TV occupied three quarters of the whole time spent in recreation and leisure activities.

A more recent study entitled EnergyProfiler [15] was developed trying to focus exclusively on the energy profiles of the Portuguese household sector. This study was based upon the presupposition that there is a need to change current energy consumption patterns, increase the knowledge over this subject and constitutes a reason to save energy and surpass barriers to enable decisions for saving energy. In [15] aimed to identify consumer profiles, classifying itself as the first Portuguese study to identify the typology and household profiles of the household sector based on a statistical analysis considering social-economic factors and psychosocial factors.

This study identified five types of household consumers, namely, receptive to energy efficiency, action oriented, responsibility diffusers, energy responsible and energy efficient which were split by sex, age and region. Despite the very positive type of profiles found by the authors it is stated that there is still the need to embrace awareness programs regarding:

Political measures:

- Programs that allow to value the energy efficiency factor in times of increased investment;
- Additional information in labeling;
- Measures and partnerships promoted by PPEC and ERSE;
- Programs based on incentives;
- Programs that encourage the purchase of more energy efficient technologies.

And, Behavioral programs:

- Promotion of knowledge concerning concrete actions for energy savings;
- Promotion of individual responsibility;
- Promotion of active and continued information;
- Increase of the knowledge of the population regarding their own consumption;
- More and better information in retailers;
- Specific consumer information to the identified profiles;
- Invest towards education of the younger population.

Regulatory Framework

The fourth branch highlights the regulatory framework according to which commercial relations are regulated in the Portuguese electric sector and presents the contribution of the measurement, reading and data availability guide in Portugal.

The regulation of commercial relations (RRC) set by the Portuguese regulator of energy services (ERSE) was approved by [16] and published in the [17] establishes that the responsibility for approving the measuring, reading and data disposition guide belongs to ERSE.

With the approval of this regulatory instrument [17] it is intended to systematize in a single document several matters relating to the measurement of electricity, reading of the measuring equipment and provision of data to the agents acting in the electricity market.

According to [18] the approval of the measuring, reading and data disposition guide is particularly important in a fully liberalized electricity market which requires full transparency and exemption in the activities of network operators, responsible for the supply, installation and reading measuring equipment, as well as for validating and segregating data consumption associated with client portfolios of suppliers on the market regime.

It is detached for the purposes of this study the importance of the information contained in [19] regarding the data processing in (only) Low Voltage (LV), including the estimates of consumption and the methodological approach for consumption profiles.

The consumption profiles are applied to all final customers that do not have a measurement equipment with the capacity to register consumption in periods of 15 minutes. The estimation of consumption broken down in periods of 15 minutes is made from consumption recorded in other final customers measurement equipment or estimated, and the final profile applicable.

There are two sets of LV profiles, initial and final. The ERSE profiles (initial profiles) and the reference load diagrams are approved and published yearly by this entity after the joint presentation by network operators.

The end profiles are obtained by adjusting the initial profiles, based on variations between the Load Reference Diagram and the System Load Diagram. With this adjustment is intended to minimize the mistakes eventually created by load fluctuations due to unpredictable factors such as temperature and luminosity. These profiles are made available by Redes Energéticas Nacionais (REN).

There are three regular LV profiles, namely:

- Class A profile for costumers with contracted power above 13.8 kVA;
- Class B profile for costumers with contracted power below or equal to 13.8 kVA and annual consumption above 7140 kWh;
- Class C profile for clients with contracted power below or equal to 13.8 kVA and annual consumption inferior to 7140 kWh.

According to [20] the profiles are prepared in a monthly basis, so it is expected that during each month:

- all workdays assume a similar load shape;
- Saturdays and Sundays have particular profiles and also different from each other;
- in the presence of a holiday, the associated profile assumes a profile similar to a Sunday.

The last report provided by ERSE is referred in [21]. This report intends to present the assumptions that comprise the different tariff schemes for the year of 2013, as well as, the premises considered for defining the typical load diagrams used for the tariff calculation, according to the tariff regulation [22].

It will be referred next a summary table listing the studies that were mentioned in this article including, year, reference number, target region, suggestion of DSM and DR actions, if the study includes behavior evaluation, if electrical energy consumption is characterized and finally if a typical load profile is provided.

Year	Reference	Target	Suggests DSM actions	Suggests DR actions	Studies regarding behavior	Characterizes Electrical Energy Consumption	Presents a typical load profile
2001	[12]	Portugal	✗	✗	✓	✗	✗
2002	[3]	EU	✓	✗	✗	✓	✓
2004	[9]	Portugal	✓	✗	✗	✓	✓
2007	[5]	Portugal	✓	✗	✗	✓	✗
2008	[6]	EU	✓	✗	✗	✓	✓
2009	[10]	Portugal	✓	✗	✗	✓	✗
2010	[7]	EU	✓	✗	✗	✓	✗
2011	[15]	Portugal	✓	✗	✓	✗	✗
2011	[1]	Portugal	✗	✗	✗	✓	✗
2011	[19] & [22]	Portugal	✗	✗	✗	✗	✓
2012	[2]	Portugal	✗	✓	✗	✓	✓
2012	[21]	Portugal	✗	✗	✗	✓	✓

Table 1 – Review of studies regarding electrical energy usage/influence for the Portuguese household sector.

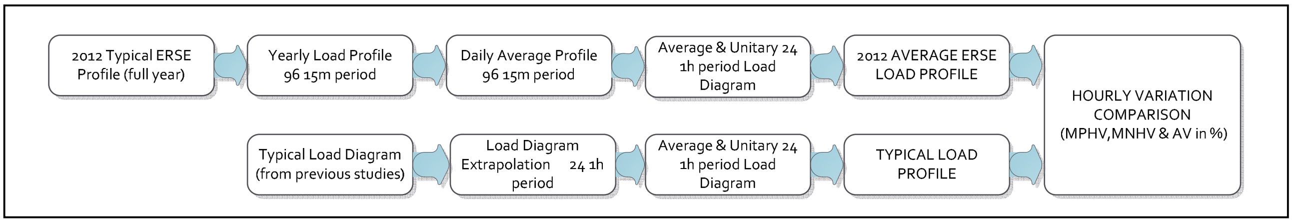
Methodology for evaluating profiles

The purpose of this methodology is to provide a simple evaluation procedure for the comparison of load profiles of the residential sector with the ability to be benchmarked by reference studies that developed a load diagram. The general idea consists in comparing the load profiles which are approved for the civil year by the Portuguese national energy regulator (ERSE)[1], before the changes provided by the transmission operator (REN)[2] caused by load fluctuations due to unpredictable factors such as temperature and luminosity, with typical load profiles provided by load research studies.

The profiles provided by ERSE and REN are comprised, for each profile and for each day of the year, by a 15 minute sampling represented in the per-unit system and is also provided the power value for the reference profile for the same period.

This methodology can be applicable to end-use global load diagrams as in [9] or typical/average individual end-use load profiles as in [6]. The fitting operations are represented in the following flowchart.

Figure 2 - Fitting operation flowchart for the profile comparison.



In order to compare the profiles it will be necessary to place them with the same sum, average and integration periods (96 15 minute periods to 24 1 hour period).

The evaluation comprised in Figure 2 provides the hourly difference between the load profile from ERSE with other chosen profile with the attainment of the maximum positive hourly variation (MPHV), the maximum negative hourly variation (MNHV) and the average variation (AV) for the profiles under study.After this initial investigation it is possible to try to assemble another load diagram on top of the ERSE profile, using available information (e.g., yearly domestic average electrical energy consumption) combined with the hourly weight of each load) and estimate the region or city per end-use energy, as in Figure 3.

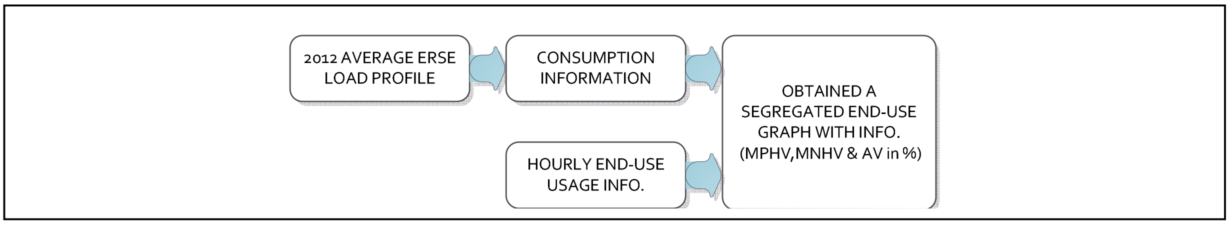


Figure 3 - Methodology for obtaining an average day city segregated electrical energy consumption load diagram.

The average load diagram that is provided with this methodology benefits from the information provided by the study of the comparison between load profiles, namely, MPHV, MHNV and AV.

Results

As stated previously the load research studies considered here are produced with different methodologies, techniques, time-span and even target audience so it is required some caution while comparing end-use results.

For example, in [9] and [2] the end-use results were produced based on previous studies, e.g. [3], and it forecasted the increase of the role of electricity in the residential sector, the replacement of already older appliances/equipment and the application of *kill bill* measures (especially DSM). Another unknown mentioned in [9] was the impact of the, at the time, new thermal and energy regulation for buildings and the usage consequences for heating, ventilation and air conditioning (HVAC). This change, associated also with the increased thermal comfort required by people led to an increase in the percentages of

[1] www.erse.pt
[2] www.ren.pt

electrical heating/cooling as shown in [6] and more recently in [1]. These end-use percentages are represented in Table 2.

<table>
<tr><th rowspan="2">Serial #</th><th rowspan="2">End-use description</th><th colspan="4">Study</th></tr>
<tr><th>[9] [%]</th><th>[6] [%]</th><th>[2] [%]</th><th>[1] [%]</th></tr>
<tr><td>1</td><td>Cold Appliances [%]</td><td>29,11</td><td>24,89</td><td>26,65</td><td rowspan="5">40,50</td></tr>
<tr><td>2</td><td>Clothes washer [%]</td><td>4,27</td><td rowspan="3">16,40</td><td>3,94</td></tr>
<tr><td>3</td><td>Clothes dryer [%]</td><td>2,39</td><td>3,48</td></tr>
<tr><td>4</td><td>Dish washer [%]</td><td>3,25</td><td>4,05</td></tr>
<tr><td>5</td><td>Cooking equipment [%]</td><td>-</td><td>8,69</td><td>-</td></tr>
<tr><td>6</td><td>Office equipment [%]</td><td>6,73</td><td>10,33</td><td>12,21</td><td rowspan="2">32,80</td></tr>
<tr><td>7</td><td>Entertainment equipment [%]</td><td>9,84</td><td>8,57</td><td>9,01</td></tr>
<tr><td>8</td><td>Lighting equipment [%]</td><td>11,66</td><td>17,23</td><td>10,68</td><td>13,60</td></tr>
<tr><td>9</td><td>Other equipment consumption [%]</td><td>32,75</td><td>3,72</td><td>29,98</td><td>-</td></tr>
<tr><td>10</td><td>HVAC – heating [%]</td><td rowspan="2">-</td><td rowspan="2">10,18</td><td>-</td><td>9,10</td></tr>
<tr><td>11</td><td>HVAC – cooling [%]</td><td>-</td><td>1,60</td></tr>
<tr><td>12</td><td>Water heating [%]</td><td>-</td><td>-</td><td>-</td><td>2,40</td></tr>
</table>

Table 2 - Comparison between end-use weights in the average consumption of reference studies.

Evaluating the data provided by these studies and possible "matches", it can be referred the similar role assigned to refrigeration equipment with 29.11% in [9] , 24.89% in [6] and 26.65% in [2]. The combined percentage of serial #1-5 in [9] represents 39.02% while in [6] this value increases to 49.98% dropping to 40.5% in [1] while the updated values of [2] represent 38.12%.

The percentage for the office equipment (#6) and the entertainment equipment (#7) is similar in both [9], [6] and [2], but different from the announced value of 32.9% for [1]. This is justifiable because in the latter study it is also included the energy usage for the vacuum cleaner, the iron and the dehumidifier (or similar devices).

The usage ratio for the lighting equipment is similar in both three studies with an amplitude of 10.68% in [2] and 17.23% in [6].Another relevant piece of information provided by the most recent statistical study [1] estimates a 9.10% ratio for HVAC heating and a more modest 1.60% for HVAC-cooling. It is also provided in this study, for the first time, the inclusion of percentage for electrical water heating, possibly explainable due to the former government support/incentive for thermal solar in households (http://www.paineissolares.gov.pt/) that can use electricity as a backup energy. Using the methodology described in Figure 2, it was initially calculated the value for the hourly difference between the average ERSE type C profile, which is considered to be the profile (among those provided by ERSE/REN) that can better represent/describe electrical consumption in Portuguese households and the adjusted average REN profile. This evaluation is demonstrated in Figure 4 for the 2012 values of these profiles covering the full year for the ERSE profile and the period of the first of January to the thirty-first of September for the REN profile.

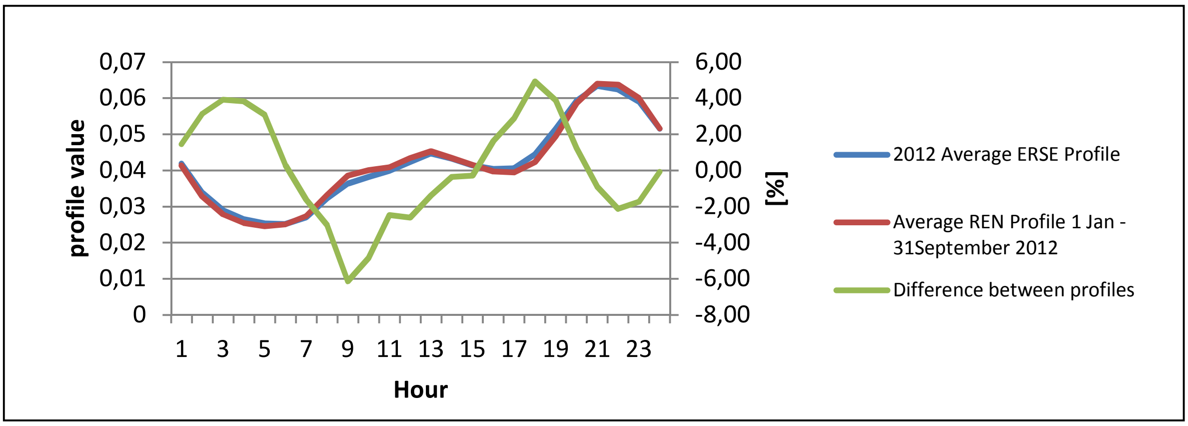


Figure 4 – Comparison between type C average ERSE and REN profiles.

It was found, for the ERSE and REN profiles, a maximum positive hourly variation (MPHV) of 4.93% and a maximum negative hourly variation (MNHV) of -6.14% and an average variation (AV) of 0.11%. These figures (and similarity) demonstrate the reliability of the initial values provided by the ERSE profile.

The following profile comparison (Figure 5) considers the EEESECR2004 original profile of [9] which represents an average for the total demand segregated by end-use for the Portuguese household sector in 2004. It was reached and MPHV of 17.26%, and an MNHV of -28.91% with an average variation of -1.16%.

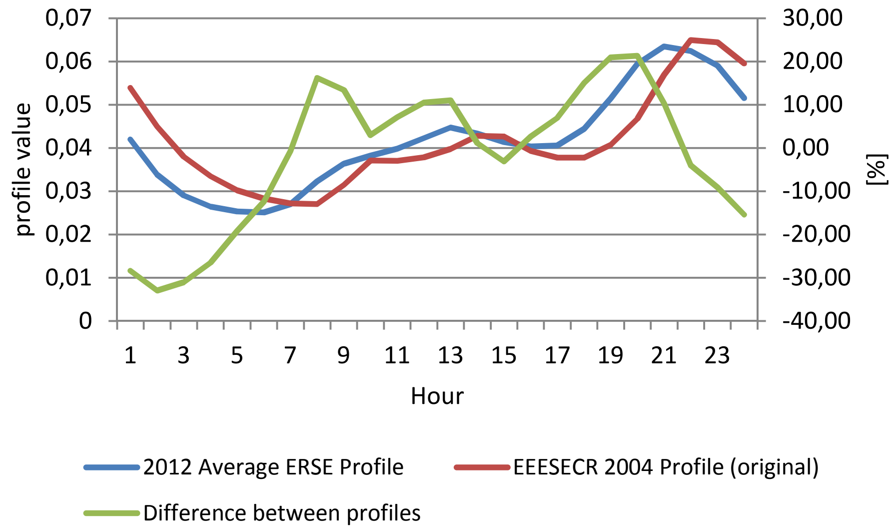


Figure 5 - Comparison between type C average ERSE for 2012 and the EEESECR2004 original profiles.

In Figure 6 it is compared the ERSE type C profile with the updated values provided by [2]. It was achieved an MPHV of 20.39% and an MNHV of -36.32% with an average variation of -1.40%.

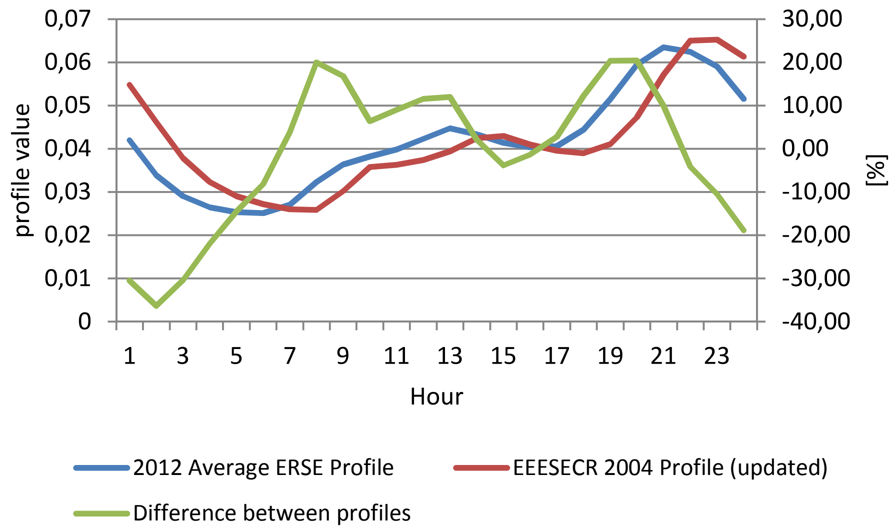


Figure 6 - Comparison between type C average ERSE for 2012 and the EEESECR2004 updated profiles.

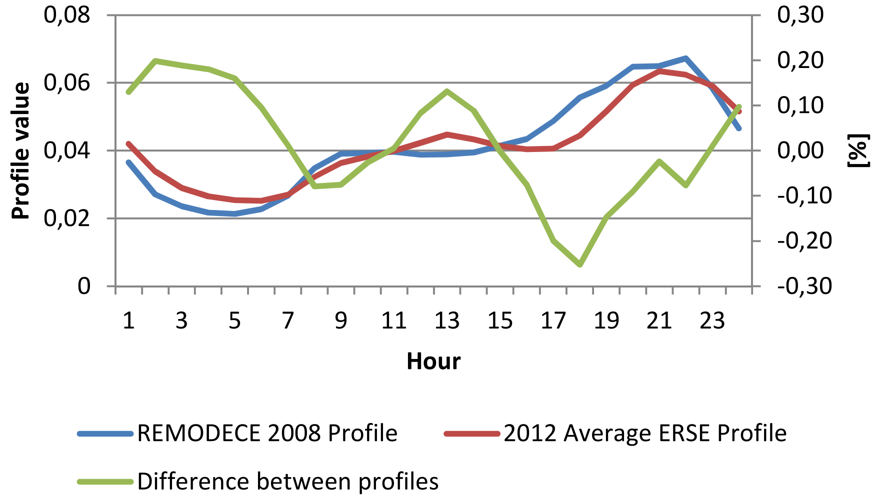


Figure 7 - Comparison between type C average ERSE for 2012 and the REMODECE2008 profiles.

It is shown in Figure 7 the comparison between the ERSE type C profile and the REMODECE2008 diagram which represents a residential European average profile by end-use for a typical day in Europe.

The MPHV and MNHV percentages are further to the ERSE profile if compared to the REMODECE2008 than in EEESECR2004 with 19.84% and -25.27% and an AV of 1.36%.

Within this methodology and considering the concept for the regulated load profile it is also possible to evaluate/compare the profiles provided by [9] and [6] with the ERSE profile multiplied by the integral of consumption over time for each load diagram provided by the studies. Since the load profiles have the same sum and average, the MPHV, MNHV and AV are equal to the unitary vector counterparts.

Comparing the 2012 type C ERSE profile with:	Maximum Positive Hourly Variation [%]	Maximum Negative Hourly Variation [%]	Average Variation [%]
2012 REN type C average profile (inserir referência previamente)	4.93	-6.14	0.11
[9] (EEESECR2004 original)	21.31	-32.94	-1.81
[2] (EEESECR2004 updated)	20.39	-36.21	-1.40
[6] (REMODECE)	19.84	-25.27	1.36

Table 3 - Summary table of the differences between profiles.

In [2] the author used the updated rates of possession of [1] to change the hourly end-use impact of the consumption diagram presented by [9].

Using this information and splitting the household equipment in different types of control, namely, schedulable and interruptible, interruptible and parameterizable and not controllable loads [23] [24] [25] it is possible to verify that in average it is possible to exert some kind of control over 48,79%.

Type of loads [%]							
Schedulable & Interruptible			**Interruptible and Parameterizable**		**Not controlable**		
Clothes Washer	**Dish Washer**	**Clothes dryer**	**Lighting**	**Cold Appliances**	**Office Equipment**	**Entertainment Equipment**	**Other Applications**
3,94	4,05	3,48	10,68	26,65	12,21	9,01	29,98
11,46			37,33		51,21		

Table 4 - Type of load by possibility of control.

City	Average Electrical Consumption [kWh/year]	# Domestic Electricity Consumers	Total domestic consumption (kWh]	Total electric consumption [kWh]
Coimbra	2.966,10	76.642	227.327.836,20	807.695.514

Table 5 - Electric domestic consumption in the City of Coimbra for the year of 2010 (PORDATA).

The fitting process considered the updated rate of appliances of [2]. The hourly impact (percentage) of each appliance/equipment is maintained. Using the methodology represented in Figure 3, this is multiplied by the power value for each hour, the value per equipment is obtained for a specific city.

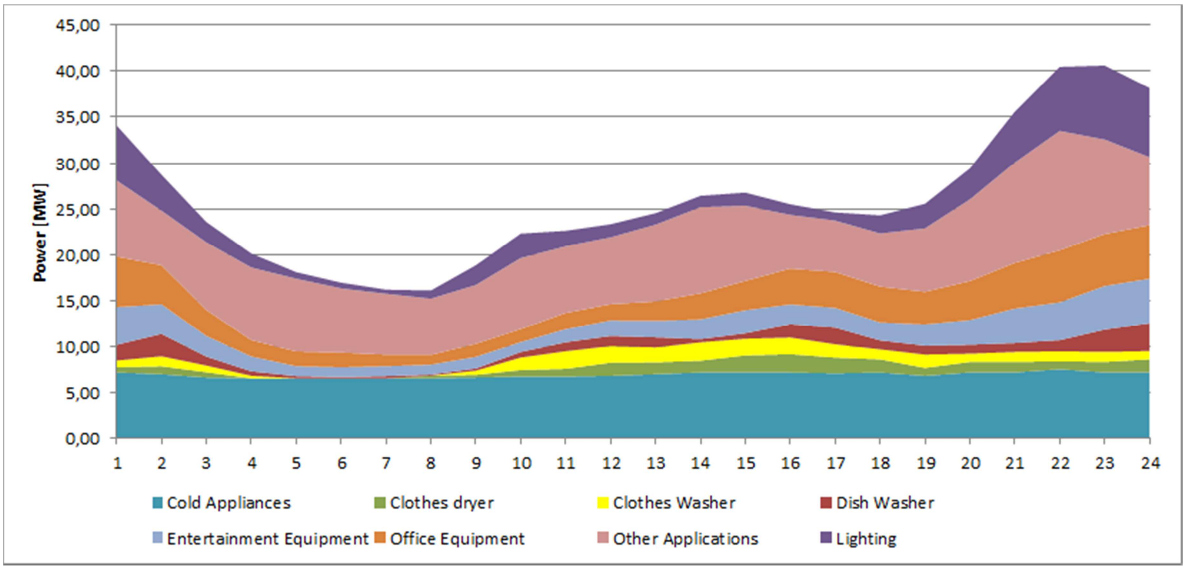


Figure 8 – Estimation of the distribution of electrical energy for the average day for the city of Coimbra with loads represented by decreasing regularity of the standard deviation.

This consumption end use graph is obtained with an MPHV of 20.39%, MNHV of -36.21% and AV of -1.40%.

Conclusions

From the obtained results it is possible to conclude that it is possible to relate the regulated typical profiles with profiles provided by load research studies considering the variation/difference among them.

The advantages of the developed methodology aims to be capable to provide the smart-grid range of value for the Energy Box per Municipality, considering MPHV, MNHV and AV, by using information regarding: the electrical energy consumption, the existence of regulated consumption profiles, the hourly information regarding the average energy usage of households.

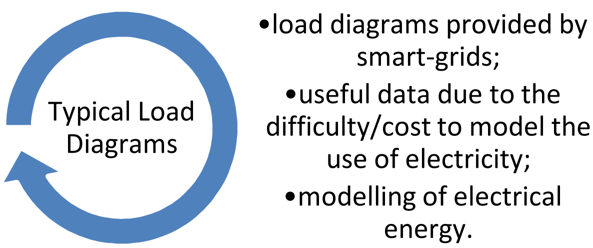


Figure 9 - Usefulness of this procedure.

It is expected that in the near future this procedure can evolve to a methodology that can also make use of the information provided by other regulated profiles like the photovoltaic micro-generation model, also provided by ERSE, as well as to include electric energy storage, e.g. electric vehicles.

The information provided by this methodology can be updated every year and be used to model the importance of each end-use therefore enabling the study of DSM and DR actions.

The current disadvantages/limitations of this methodology is the fact that it is assumed the national percentage of equipment/appliances and hourly rate of consumption for all Portugal Continental. Another existent disadvantage is that it is provided an average value for the whole year, not allowing, yet, an evaluation for the different seasons of the year.

Acknowledgements

This work has been framed under the Energy for Sustainability Initiative of the University of Coimbra and supported by the Energy and Mobility for Sustainable Regions Project CENTRO-07-0224-FEDER-002004 and Fundação para a Ciência e a Tecnologia (FCT) under grant SFRH/BD/88127/2012, and project grants MIT/SET/0018/2009 and PEst-C/EEI/UI0308/2011.

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Energy and Economic Optimization to Achieve Near Zero Energy Homes in Europe: Implications of Inclusion of Lighting and Appliances

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Abstract

Achieving annual net zero energy use in homes has been demonstrated as feasible in dozens of monitored projects in the United States.[1] In particular, very low energy use homes in Europe have been proven within the *Passivhaus* approach.[2] Achieving "nearly zero energy buildings" (NZEB) has also been established as a vital objective over the next decade within the European Union (EU) (Boermans et al., 2011). However, reaching this result at the lowest possible cost remains a key challenge around the world. Balancing renewable power generation with energy efficiency will be vital in Europe as anticipated by Voss, Musall and Lichtmeβ.[4] We describe new energy optimization software, *EnergyGauge: CostOpt* developed to address this need. The model performs detailed hourly sequential simulations showing how to achieve very low or zero energy home designs at the lowest possible cost in a variety of climates. The model can be used either for optimization of new or existing homes, which often have very different costs for various envelope measures. We have adapted the model to run in European climates and demonstrate it here simulating existing homes in 31 representative locations. A key result of our investigation is that energy reductions of 70-100% are economically feasible for existing EU residences. Finally, we illustrate how exclusion of lighting and appliances results in sub-optimal solutions, particularly for electricity use which has a disproportionate impact on greenhouse gas emissions. The results have important implications for the NZEB target established by the EU.

Building Energy Simulation and Optimization Model

The calculation model in *EnergyGauge* is rigorous, using the powerful hourly energy simulation, DOE-2.1E developed by the Lawrence Berkeley National Laboratory.[5] This model estimates household heating, cooling, water heating and appliance loads by each hour. Fundamental building thermodynamics are estimated via transfer functions using a multi-zone representation. A variety of fuels can be simulated. The simulation has been indexed to real buildings to verify its potential to replicate measured energy use in cold versus hot climates.[6] The simulation model has been adapted to run in European climates by adding the needed hourly IWEC weather data files, converting to metric inputs and modifying cost data into a Euro format. Using similar inputs, favorable comparisons have also been produced against the Passivhaus Planning Package (PHPP) software.[7] The economic optimization method is consistent with established procedures for Nearly Zero Energy Buildings in the EU (OJ C 2010/31/EU).

For use with the optimization, we developed nearly one hundred energy conservation measures (ECMs) including insulation, window types, air tightness, heating, cooling, water heating, appliances and lighting. This includes a comprehensive cost database with measure characteristics, life, operation and maintenance and cost. Renewable energy production is evaluated using a photovoltaic (PV) simulation (PVFORM) and a prediction of solar water heating performance based on hourly correlations to the TRNSYS model. For a given location, this allows the cost effectiveness of energy efficiency measures to compete directly with the cost of renewable energy production to determine the least cost path to near zero energy. Even in cold climates, this method may offer some advantages against the more standard *Passivhaus* approach as it is may be possible to reach zero energy performance at similar cost.[8]

The optimization model evaluates the entire suite of options (typically 50-100 measures), selects the option with the highest benefit to cost net present value ratio (termed the Saving to Investment Ratio or SIR), incorporates this option, and then re-simulates all available options. The process continues in this manner until an SIR or 1.0 is reached or until zero energy is achieved using PV resources.

Within our example, an existing home in poor condition is optimized for Berlin, Germany, selecting from available ECMs. The simulated energy demand from each fuel along with the cost data are used to analyze the cost effectiveness of individual measures using the SIR metric. For existing homes, the analysis can consider two different scenarios: a) outright retrofit of existing components and equipment at full cost or b) incremental cost at time of natural replacement.

The cost effectiveness calculations are based on the present value of the life-cycle costs and benefits of the measures over an analysis period of 30 years. The procedures for estimating the life cycle cost calculations are well documented.[9] The assumed economic parameters for the example analysis are shown in Table 1 are based recommended guidelines supplementing Directive 2010/31/EU. The assumed costs, service lives, and maintenance fractions for each of the 75 considered retrofit measures considered are given in an easy to alter Excel spreadsheet which feeds the simulation. The analysis can conducted assuming that retrofit measures are purchased either outright, or through financing, the period of which can be varied. The assumed economic evaluation rates for the calculations presented here are given in Table 1 below as consistent with suggested macroeconomic trends.[10] The value for the energy price inflation rate implicitly approximates the EU Emissions Trading scheme with carbon pricing assumptions of 25€/tCO_2 in 2020 to 39€/tCO_2 in 2020.

Table 1. Economic Parameters for Optimization

Category	Rate
General Inflation Rate (GR)	2.0%
Energy Price Inflation Rate (ER)	3.0%
Financing Interest Rate (MR)	5.0%
Discount Rate (DR)	5.0%
Down Payment with Financing	10.0%
Current Electricity Price	€0.26/kWh
Current Natural Gas Price	€17.70/ GJ

The physical building and economic parameters are easily modified for analysis; adding measures or combinations of measures to the library is straightforward. Depending on climate and building efficiency starting point, approximately 250-500 simulations with 5-25 iterations are required to reach the optimal set of building characteristics. A complete optimization takes approximately one to two hours on a desktop computer.

Example Results: Optimization of an Existing Home in Berlin

We illustrate the optimization approach for Berlin in a very poorly insulated existing 150 m^2 home loosely based on the prototype description in a recent study by Ecofys GmbH and the Danish Building Research Institute.[3] Fundamental characteristics are summarized in Table 2.

Table 2. Characteristics of Poorly Insulated Home for Optimization Example

House Size	150 m^2 over 2.5 m unheated cellar
Windows	23 m^2 double clear glass with significant air leakage (~3.0 W/m^2K)
Walls	Un-insulated frame walls (~2.8 W/m^2K)
Attic	R-3.3 existing insulation (~0.25 W/m^2K
Doors	Un-insulated wood entry door (~2.8 W/m^2K)
Air Leakage	Very leaky (8 ACH @ 50Pa blower door pressure)
Heating	Hydronic natural gas heating system,75% efficiency
Cooling	COP 2.9 mini-split cooling system in climates requiring cooling (not in Berlin)
Settings	20^oC for heating, 18^oC from 11 PM to 6 AM daily; cooling 26^oC
Hot Water	155 l poorly insulated hot water tank in cellar providing 150 l per day @ 55^oC
Appliances	Standard clothes dryer, washer, dishwasher, televisions etc.
Lighting	85% incandescent lamps (15% fluorescent)

The inefficient baseline existing home is predicted to use 4,077 kWh per year and 124 GJ of natural gas for space and water heating and cooking (space heat is approximately 100 GJ). For our initial analysis, cost data is based on a database of the cost of various efficiency measures developed by the U.S. National Renewable Energy Laboratory and converted to Euros (http://www.nrel.gov/ap/retrofits/about.cfm). This was refined by review of costs in Europe for various components and equipment.

Rather than regional prices for electricity and fuels, for this evaluation we use a consistent price so that climate-related differences are highlighted. Representative energy costs for electricity and natural gas were taken from the Eurostat website (http://epp.eurostat.ec.europa.eu/). As such, the analysis presented here is more illustrative of the method and approach, rather than a definitive evaluation for specific locations.

No financial incentives were assumed for either efficiency or renewable energy sources so all can be evaluated on a fair playing field. However, differing measure life is specified for each measure. For instance, most insulation measures are assumed to last at least 50 years as opposed to renewable energy systems which might last 20-30 years and require operation and maintenance during that time and replacement before the end of the analysis period. A key leverage point in the analysis is that if PV electricity system is specified, its cost effectiveness becomes the key economic test for other competing measures, which should be installed before the PV system is considered.

The final selected options comprise insulating the un-insulated walls to R-2.3, improving ceiling insulation to R-8.6, insulating the cellar on the interior, a better insulated entrance door, substantially reducing building air leakage, a 96% efficiency fully condensing gas boiler and with improved pipe insulation, modern hot water saving plumbing fixtures,100% efficient lighting and an energy efficient clothes dryer. After the measure selection, a 4 kW grid-connected PV system is installed that more than produces all the electricity needed by the site.

Our example analysis shows the capability to achieve approximately an 80% energy savings in Berlin with cost effective retrofits at a lower cost than the current building, paying for energy costs without the improvements. The measures selected were as follows:

Table 3. Selected Order of Measures for Berlin Optimization Example

Code	Description
AirSealing	Building air leakage reduced from 8 ACH@50Pa to 4 ACH
FrmWR-2.3	Insulate un-insulated wall cavities to R-2.3 (drill & fill system)
CeilR5.3	Increase ceiling insulation level from R-3.3 to R-5.3
CeilR6.7	Increase ceiling insulation level from R-5.3 to R-6.7
Pipeins	Insulate exposed hot water piping in the cellar (R-1)
LowFlSho	Change plumbing fixtures to modern low flow fixtures
InsDoor	Retrofit existing un-insulated door to R-1 insulated model
BsmtWR3.3	Retrofit R-3.3 insulation to the interior of the cellar walls with finished wallboard
Tighter	Building air leakage reduced from 4 ACH@50Pa to 3 ACH
CeilR8.6	Increase ceiling insulation level from R-6.7 to R-8.6
100% Lights	Convert all interior lighting to compact fluorescent or LED sources
Ef_Dryer	Install Class A heat pump clothes dryer
Eff Washer	Add Class A energy efficient clothes washer
Boiler-96%	96% efficient condensing boiler installed
4kW-PV	Add 4 kW_{dc} roof-top photovoltaic system with 95% efficiency inverter

The selected package of measures in the example had a total costs of €28,050 of which the turnkey 4-kW PV system was €14,700. The efficiency improvements reduced household natural gas use by 61% (125 to 49 GJ annually) and electricity consumption by 33% (3,853 to 2,599 kWh/yr). After the efficiency improvements, a 4 kW PV system is able to produce more electricity (3,684 kWh/yr) than the improved home uses annually.

The combined total annual source energy required, considering both efficiency improvements and renewable power generation, is cut by 77% resulting in a reduction in annual CO_2 emissions from the household of approximately 7 metric tonnes.

It should be noted that, the cost of improving existing buildings can be much greater than for new ones for certain building elements such as walls, air sealing and elimination of thermal bridges. To the extent that the cost data base reflects these differences, the selection by the optimization model will be dramatically different for new buildings which will typically more resemble *Passivhaus* levels of air tightness and insulation in Europe. Figure 1-3 detail the results of the optimization as sequential measures are selected for the example retrofitted house.

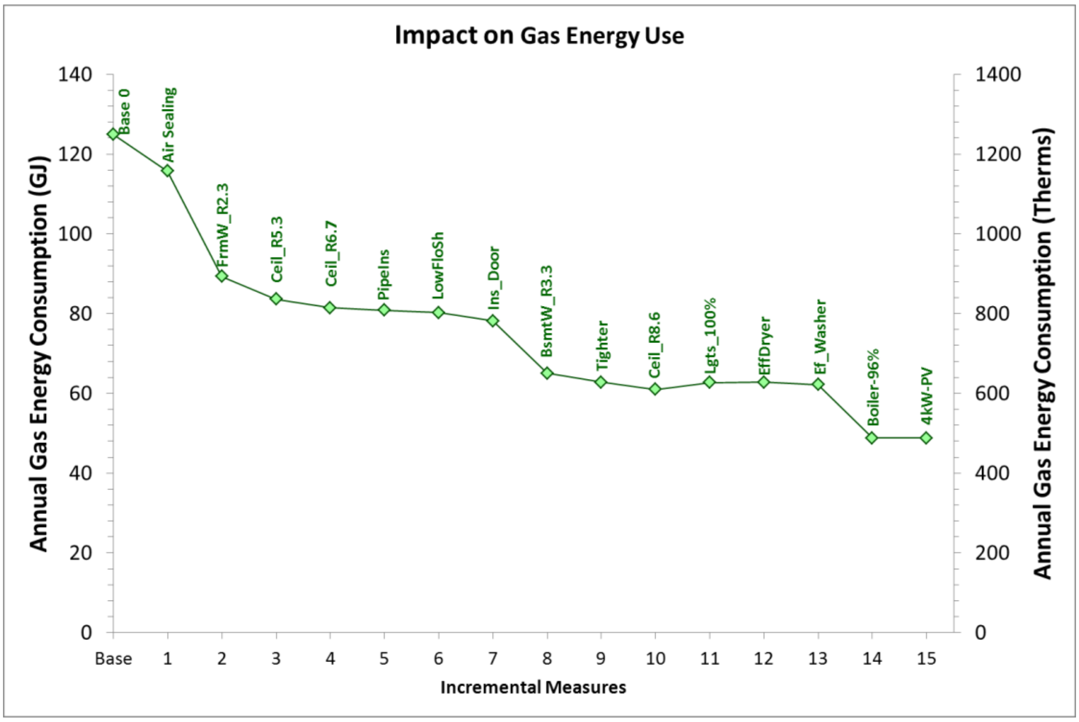

Figure 1. Impact of Optimization Measures on Household Natural Gas Consumption

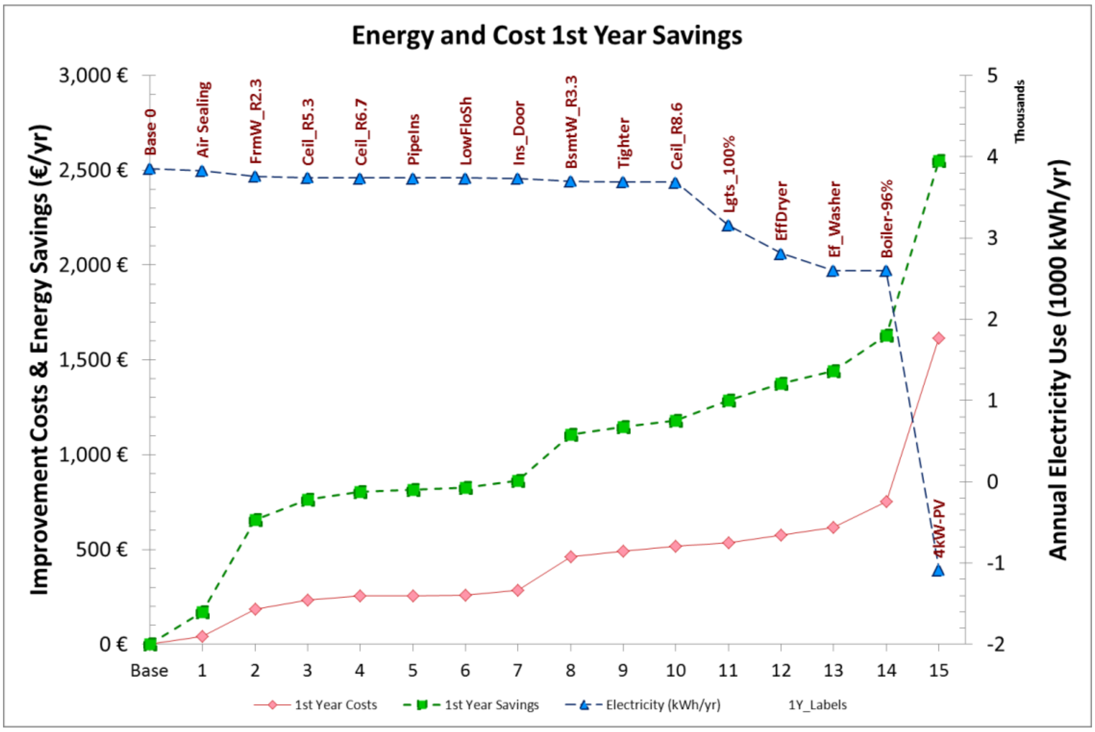

Figure 2: Impact of Optimized Measures on Electricity Use and First Year Annualized Costs

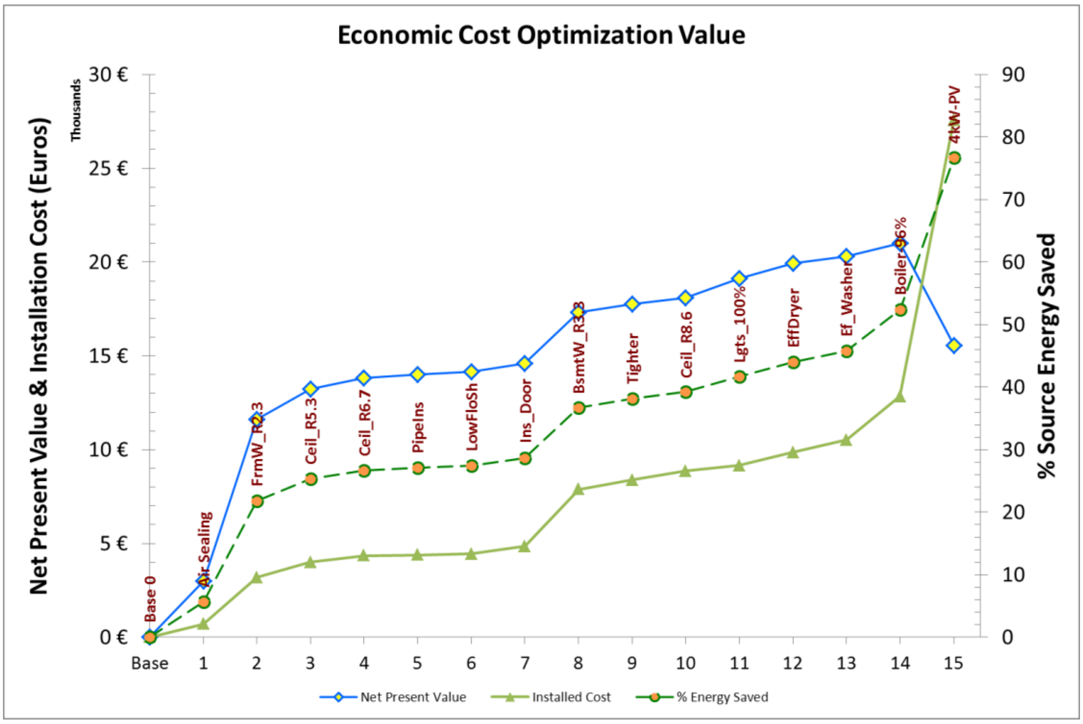

Figure 3: Impact of Optimization on Net Present Value, Percent Energy Saved and Installed Cost

Sensitivity of Optimization Results to Climate

The above analysis was duplicated with the same building and assumptions in Madrid, Spain. In that sunny location, the 4-kW PV system shows much greater output (6,096 kWh/year). Also, the home itself shows greater electrical loads due to cooling- 4,990 kWh which are cut by installed efficiency measures to 3,303 kWh—a 34% reduction. With Madrid's milder weather, gas consumptions starts out at 70 GJ and is reduced by 56% to 31 GJ. The final selected options were similar to those selected for Berlin although with less emphasis on air tightness—a reflection of the milder climate.

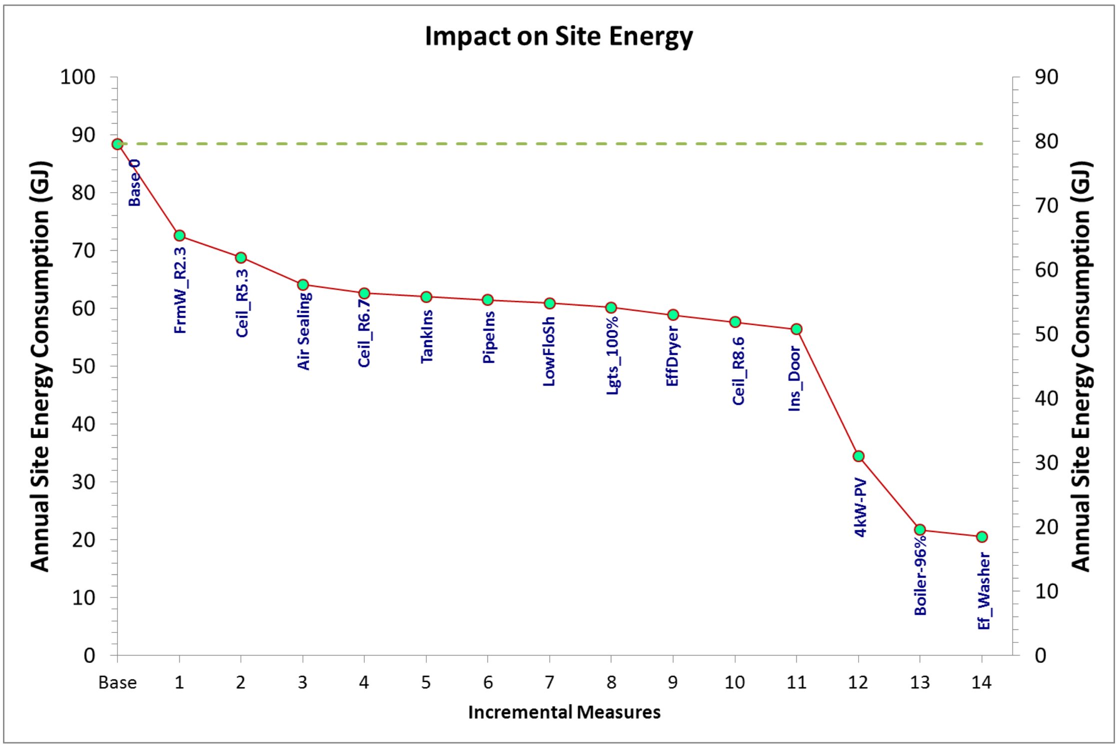

Figure 4: Reduction in Site Energy by Optimization in Madrid, Spain

Total source energy and associated emissions in Madrid are reduced by 100% with a cost of the full package of measures of €24,100. Figure 4 above shows the results in terms of the reduced site energy. There are also financial advantages. The homeowner annually saves approximately €1,288 the first year even after accounting for interest expenses.

It should be noted that including a PV system in the analysis can truncate efficiency measures which are less cost effective than generating the same savings from the solar system. Although not shown here, an optimization for Rome, Italy shows less ceiling insulation and air tightness justified beyond that in Berlin before installing the PV system, because of increased solar electrical output and milder heating-related consumption. Similarly, the same evaluation for Oslo, Norway or Tampere, Finland justifies greater insulation efficiency levels due to the extreme climate and lower PV output.

Table 4 shows the comparative predicted energy use for the unimproved prototype building along with the PV output from the 4 kW PV system as well as the optimized near zero energy building in 31 selected European locations. Although the building stock, appliance saturation and fuels used vary by location (for instance most Norwegian homes are electrically heated due to low-cost hydroelectric power), such evaluation gives an idea of the physical influences of climate severity against the solar PV resource.

Table 4: Predicted Initial Electricity, Natural Gas and PV electric output in 31 Locations for Base and Optimized Near Zero Energy Buildings in 31 Locations

IWEC Location	-------Base Building------		-----Optimized Near Zero Energy Building-----			
	Annual Electricity (kWh)	Annual Natural Gas (GJ)	Solar PVH (KWh)	Annual Net (kWh)	Natural Gas (GJ)	Source Savings (%)
Amsterdam, NLD	3,833	118	3,724	-970	44	79%
Athens, GRC	5,896*	46	6,170	-2,006	20	102%
Berlin, DEU	3,853	125	3,684	-1,084	49	77%
Bremen, DEU	3,875	134	3,608	-796	51	76%
Brussels, BEL	3,830	116	3,361	-597	45	76%
Copenhagen, DNK	3,897	143	3,792	-733	55	75%
Debrecen, HUN	3,829	115	4,711	-1,947	45	85%
Frankfurt, DEU	3,383	118	3,873	-1,195	46	79%
Köln, DEU	3,833	118	3,587	-823	45	78%
Geneva, CHE	3,810	108	4,410	-1,665	42	84%
Hamburg, DEU	3,868	131	3,604	-787	51	76%
Kiev, UKR	3,895	141	4,633	-1,565	56	79%
Linz, AUT	3,858	127	4,153	-1,344	50	79%
Lisbon, PRT	4,247*	39	6,301	-3,402	20	120%
London, GBR	3,810	109	3,832	-1,105	40	81%
Madrid, ESP	4,990*	70	6,096	-2,793	31	100%
Moscow, RUS	3,976	172	3,732	-782	43	84%
Munich, DEU	3,887	138	4,248	-1,296	54	78%
Oslo, NOR	3,940	158	3,438	-429	50	78%
Paris, FRA	3,798	104	3,941	-1,215	40	82%
Palermo, ITA	5,756*	28	6,304	-2,276	14	111%
Prague, CZE	3,904	145	3,523	-565	44	80%
Rome, ITA	4,785*	52	5,562	-2,630	25	103%
Salzburg, AUT	3,851	124	3,987	-1,190	49	79%
Seville, ESP	6,139*	32	6,576	-2,514	15	113%
Sofia, BGR	3,829	115	4,013	-1,246	44	80%
Stockholm, SWE	3,949	162	3,664	-656	47	81%
Stuttgart, DEU	3,851	125	4,139	-1,352	47	79%
Tampere, FIN	4,017	188	3,680	-913	46	85%
Vienna, AUT	3,846	122	4,223	-1,429	47	81%
Warsaw, POL	3,896	141	3,782	-834	40	82%

*Assumes cooling system is available in these locations

HAnnual output of 4 kW_{dc} photovoltaic system on unobstructed south-facing roof

If it is not desirable to judge efficiency versus renewable generation, alternate results can be obtained by deleting the PV system. Similarly, it is possible to optimize a building with no heating and/or cooling equipment upgrades available to assess the optimal building shell improvements alone. Although the EU specifies 30 years for this type of analysis, it can be argued that 50 years would be a more representative time line as many important options, such as higher levels of insulation, have very long life relative to shorter lived options. Finally, as the model has hourly output, it is possible to directly assess predicted winter and summer peak impacts of selected measures along with that of the PV element.

Influence of Incremental Measures on Optimization Results

Using the optimization model, it becomes apparent that the ratio of initial measure expense to energy savings level largely governs the resulting series selection. Service life is also a factor. This indicates the need to collect the most representative European cost data for use with future optimization.

Within an incremental analysis, also becomes clear that measures which are at the end of their useful lives are very often selected whereas they are not chosen in the “outright replacement” paradigm. This is because the cost for outright replacement to the most efficient appliance is often much greater than the incremental cost to choose the same efficient model over the standard one when it is worn out.

For instance, in the example given, if it is indicated that the heating system, dishwasher, clothes washer and refrigerator are all needing replacement, the optimization will readily choose the most efficient models for these (for instance the *Top-Runner*, or *A++* models) within the optimization whereas they are not selected otherwise.

The concept of an incremental evaluation has important implications for retrofitting existing buildings where a building-specific audit to evaluate remaining appliance and building component life may positively influence the savings potential. Based on an incremental analysis for Berlin in Figure 5, replacement of worn out windows, efficient washers, dishwasher and a more efficient heating system results in 11 GJ of additional site energy savings and 92% overall source energy savings at a lower total cost (€24,800). The same type of analysis conducted in Madrid also selected the better appliances, but improved the cooling system on replacement and also achieved more than a 100% reduction to annual source energy demand even with a smaller 3 kW PV system.

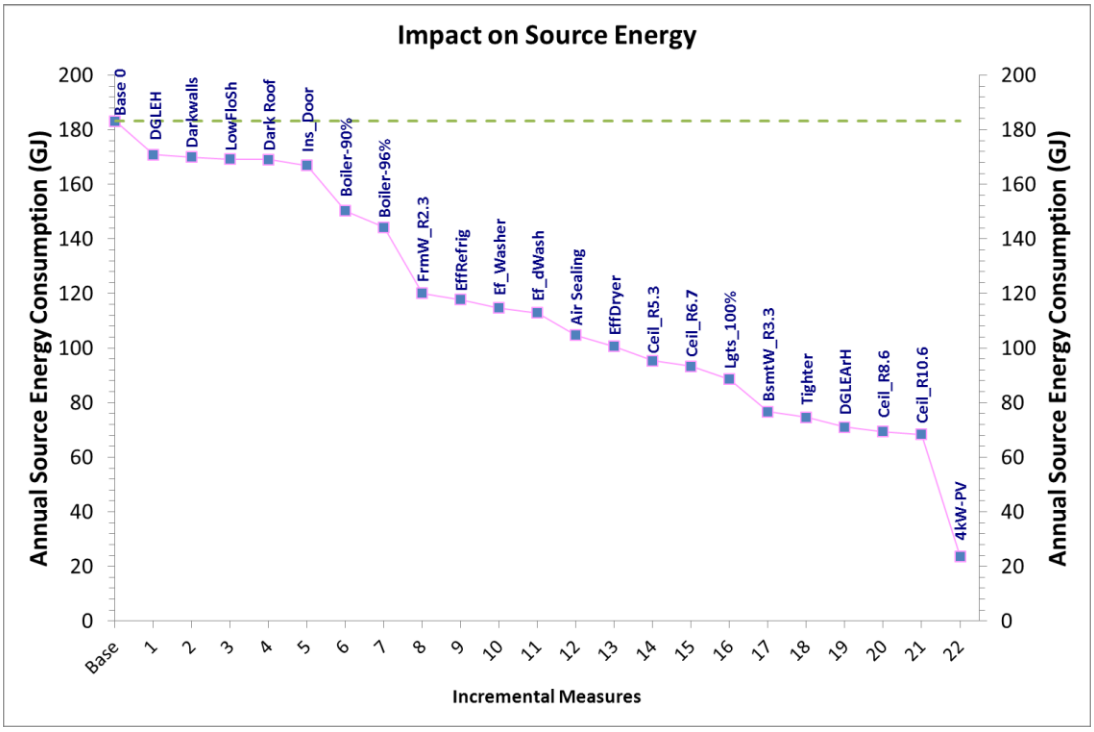

Figure 5: Source energy reduction from optimization for Berlin example with incremental costs for measures.

This approach may argue for a two-tiered analysis: one for of items that should be improved right away, along with another evaluation of those that should be upgraded to best technology at the time they reach the end of their service life.

Impact of Not Considering Appliances and Lighting in the Optimization

The current approach for locating optimal paths for achieving near zero energy buildings in the EU does not require the energy use in appliances and lighting be considered in the optimization process.[11] However, our results indicate that exclusion serves to limit achieved energy savings—particularly for electricity—and would require increase to more expensive photovoltaics to reach similar reduction levels. This is particularly true in the case of lighting where the economic advantage of CFL and LED lighting is very compelling for retrofitting existing homes.

To illustrate, we performed the same optimization analysis for Berlin and Madrid when appliances and lighting options are not available within the optimization. Achieved energy savings are lower in both locations. For the same prototype, source energy reductions are lowered from 77% to 71% in Berlin and from 113% to 93% in Madrid. In particular, not including lighting and appliances leads to compromised electricity efficiency. In Berlin eliminating lighting and appliances from consideration results a loss of economic savings of 1,311 kWh/year. This could be offset by more PV, but at a higher incremental cost. Results also showed the importance of considering appliance and lighting energy is progressively more important in warmer climates where lower internal heat gain levels can reduce potential space cooling.

Our results clearly indicate that including appliance and lighting energy in the optimization process is important to achieve nearly zero energy buildings at the lowest possible incremental cost. Moreover, this inclusion will likely become more important as the growth in home appliances and electronics continues to expand in the EU.

Summary

We describe a comprehensive energy simulation and cost optimization model that is a powerful means to find the least cost approach to achieve nearly zero energy homes. *EnergyGauge Costopt* consists of a detailed energy simulation, a detailed economic evaluation calculation and powerful optimization model. It is possible to evaluate both new and existing home designs and to consider how component remaining life influences the optimal choices for house retrofits.

We provided an example of the calculation method in action for a poorly insulated existing home in Berlin, Germany and Madrid, Spain. Parametric studies have also been completed for other European climates. We show it is possible to reach a very low energy design in existing homes with approximately a 75% - 100% source energy savings (and similar greenhouse gas reductions) at the lowest cost through using a combination of better insulation, windows, building tightness as well as improved Energy efficient Class-A appliances, lighting and home energy management systems along with a 4 kW PV system. In both locations, optimized building has less than zero net electricity consumption on an annual basis and natural gas consumption for space heating and water heating is reduced by 56% in Madrid and 61% in Berlin. However, the achievement of net electricity neutrality is only achieved if home lighting and appliances are optimized at the same time that the building “technical” systems are addressed.

While we provide a conservative economic assessment above, it is possible to alter the inputs to consider very long time horizons and/or higher energy inflation rates. The optimization can also be limited to only non-equipment related options, providing best evaluation of one-time opportunities such as building component insulation levels. It may be advisable to perform this type of optimization first since one can argue that heating, cooling and appliance systems are renewed several times during a building’s life, whereas the envelope measures are in place for a long time with few points of possible intervention.

Using the model, we find somewhat different optimization results between cold and cloudy locations, such as Berlin and sunny ones, such as Madrid. For instance, in the warmer locations, interior appliance efficiency measures are selected earlier as heating loads are not as significantly increased, and in the case of the warmest locations—cooling loads may be reduced. In colder climates, insulation and building tightness appear most important.

Such an analysis method can provide important input on how to achieve very low or zero energy homes in the European climate at the lowest possible cost. This methodology may augment the efficiency-only *Passivhaus* approach since renewable energy resources can be fairly evaluated against incremental building improvements. Similarly, important building thermal improvements are not shortchanged since the differing lifetimes of insulation, equipment and renewable energy systems can be fully taken into account within a balance approach.

Finally, we examined how excluding appliances and lighting from the optimization process, as currently allowed in the 2010/31/EU approach, impacts results. We found that such an oversight reduces the achieved savings, particularly for electricity, and increases the cost for reductions achieved. Accordingly, we recommend that the adopted EU optimization process include lighting and appliances for best results. This inclusion becomes ever more important with future growth in home appliances and electronics grows and associated greenhouse gas emissions.

Acknowledgements

Thanks to Kjell Bettgenhaüser with Ecofys for assistance collecting cost and performance data. Brian Hanson and Lixing Gu made necessary adjustments to the simulation software coding and translation of hourly weather files. Justin Khan automated the output plotting process.

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Advanced Renovation of three Residential Buildings – Evaluation of a Field Test

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Abstract

In Germany exist, towards counts from 2009, about 18 million residential buildings with altogether 39 million dwelling units. Almost 71% of those buildings were built before 1979, which means those were built before the introduction of the first heat insulation ordinance. These buildings are today a substantial part of the German building stock. Their energy consumption is very high because most of them have low insulation standard and outdated heating technology. In this work the holistic renovation and the results from the monitoring activity of three identical buildings-blocks, located in Karlsruhe, is presented.

Each block has three separate entrances (buildings), each building ten apartments over five floors. The buildings were built at the end of the fifties, had no external insulation, “single glass windows”, a single cackle stove per apartment and water flow heaters. Seven unique refurbishment layouts have been applied to the nine buildings of the three blocks. One layout is implemented for the first block (30 apartments), one layout per building in the second and the third block.

The refurbishment layouts vary in terms of insulation, heating engineering system and ventilation system. A high time resolution monitoring system collects data about the comfort conditions in the rooms, the energy flows in buildings and the status of the heating engineering systems.

In this work assets and drawbacks of the different refurbishment technologies, both at heating engineering system and at building insulation level, are analyzed and evaluated through measured data.

Introduction

In Germany exist, towards counts from 2009, about 18 million residential buildings with altogether 39 million dwelling units. Almost 71% of those buildings were built before 1979, which means those were built before the introduction of the first heat insulation ordinance. The lack of accommodations after the Second World War brought to a fast reconstruction process of residential buildings.

Figure 1. Pictures of the apartments before the refurbishment process. Left: dirt from an old cockle stove. Center: Domestic hot water flow heater. Right: Potable water pipes.

About eleven million apartments have been built in Germany between 1945 and 1965. Most of those apartments are located in big buildings and are still in use today. This large number of buildings consumes a big amount of energy due to low insulation standards and obsolete heating systems.

Since 1979, with implementation of the first Heat Insulation Ordinance (WSVO), the critical acceptable levels for new buildings standards have been tightened. At time of writing, the ordinances are far-reaching and everyone has to fulfil the EPBD 2010 - European Directive Energy Performance of Buildings which takes into account building and engineering systems together (in Germany the directive has been received into the EnEV “Energieeinsparverordnung” [1], in English “Energy Savings Ordinance” for buildings).

Figure 2. East facade of block one before (left) and after (middle) the refurbishment process. Right: Orientation and enumeration of the nine buildings over the three blocks

In this work the holistic renovation and the results from the monitoring activity of three identical buildings-blocks (Figure 1, Figure 2), located in the Quartier “Rintheim”, Karlsruhe, is presented. Each block has three separate entrances (referred as buildings), each building ten apartments over five floors (Figure 3). The blocks were built at the end of the fifties, had no external insulation, “single glass windows”, a single cockle stove per apartment and water flow heaters. Seven unique refurbishment layouts have been applied to the nine buildings of the three blocks. One layout is implemented for the first block (30 apartments), one layout per building in the second and the third block. The buildings are owned from the municipal society Volkswohnung, which own circa 12,700 rented apartments in Karlsruhe.

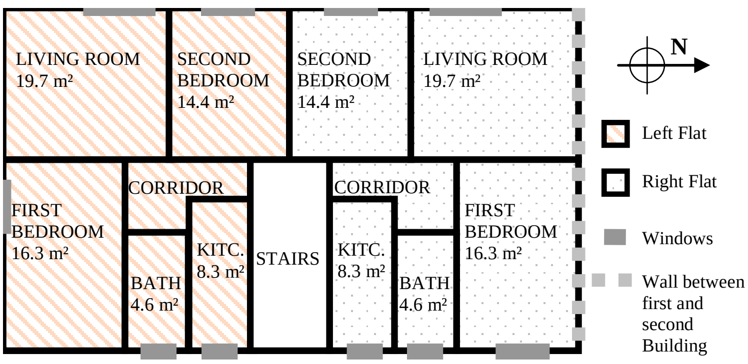

Figure 3. Floor plan of each floor.

Refurbishment layouts

The seven refurbishment layouts have been planned and implemented for the nine buildings in close collaboration with Volkswohnung Karlsruhe. The first block has been completely refurbished with a Volkswohnung developed refurbishment layout based on their own refurbishment experience; each of the other buildings are refurbished with a unique refurbishment layout.

The retrofit of the second block is based on state of the art insulation and an advanced engineering system technology, available on the market. Advanced refurbishment solutions are realized for the third block with the use of vacuum panels as external wall insulation, high efficiency heat pumps and waste heat recovery units.

The third block is designed to reach the lowest primary and final energy consumption. In Figure 4the refurbishment solutions are described in details. WHRU indicate waste heat recovery units, the number in per cent next to WHRU is the efficiency of the heat exchange process. The thermal conductivity λ of the insulation is indicated by a number in each box, for example 035 means λ=0.035 W/(mK).

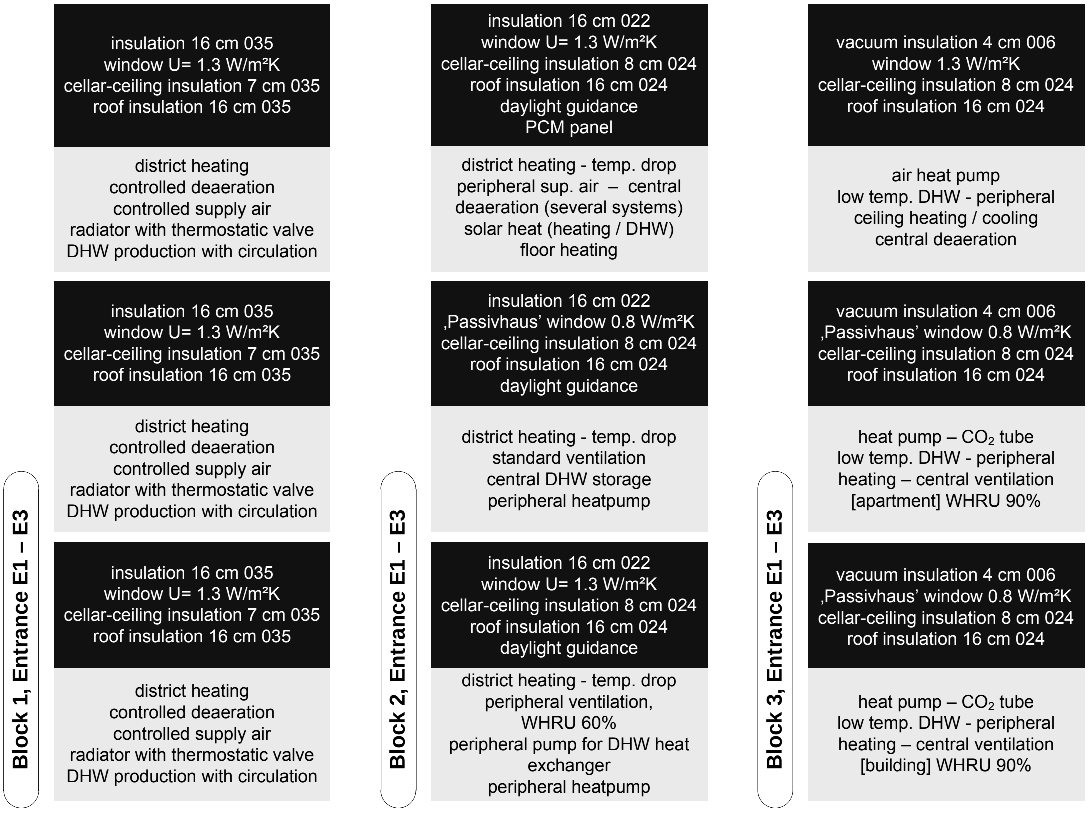

Figure 4. Refurbishment solutions: the white text on dark background is related to the thermal insulation, the dark text on grey background is related to the engineering system solution.

Monitoring System

Heating energy demand limitations for buildings should help reaching EU decarbonization goals for 2050 [2]. Through a high time resolution monitoring system it becomes possible to:

- prove how well calculated heating energy demands of buildings correlate with real heating energy consumption,
- to find out if the installed technology is working properly,
- evaluate the efficiency of each retrofit solution,
- optimize the engineering system,
- validate static and dynamic simulation models.

To reach these goals, a complex, high resolution monitoring system has been, in cooperation with the Technical University of Applied Science of Karlsruhe, planned and installed. Each room of each apartment of block 2 and block 3 is monitored in terms of:

- Room temperatures,
- room relative humidity,

- volatile organic compounds (VOC),
- carbon dioxide (CO2),
- luminosity on the roof (Lux),
- window's opening, ratio,
- infra-red/visible light(vis/IR)
- inlet air-flow temperature (through apposite windows' openings).

The energy flows are monitored through heat meters in all apartments. In addition, in four apartments per building, a heat meter per room is installed. The complete engineering system for heating and domestic hot water is monitored as well, from production up to storage and distribution, in such a way that system losses can be identified, step by step. A weather station has been installed in the field test and provides information about ambient temperature, ambient relative humidity, wind direction and velocity, luminosity and solar radiation. The monitoring system has been plant in such a way that the influence of the building construction and technical components on energy consumption and the space comfort can be determined.

The collection of the room data in the apartment is made via a bus system (M2-Bus). The monitoring system works with a time step of 60 seconds. More than five million data point per day are collected and transferred from Karlsruhe to Aachen. To provide an optimal handling of the data, these have been integrated into a HDF5 database. The HDF5 Database presents a hierarchical structure of groups (comparable to "directories" under the "Windows" operative systems) and leafs ("N x M" matrixes containing the data). One databank per month has been (since 2010) and will be generated.

The evaluation of the HDF5 databanks is executed in an own developed HDF5-viewer, based on the python HDF-Tables 0.9. This viewer offers several plotting and analysis tools. A screenshot of the viewer is shown in Figure 5.

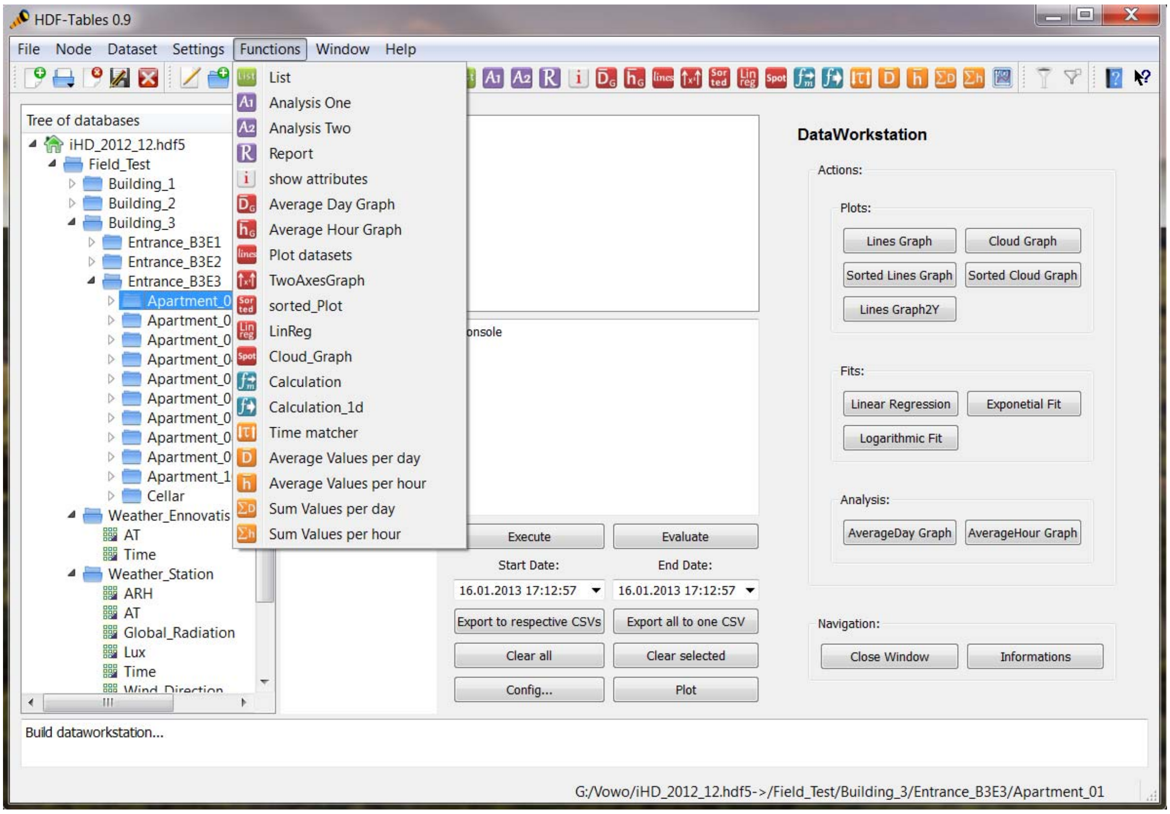

Figure 5. Screenshot from the own developed HDF5 Viewer. The tree of databases shows the HDF5 od December 2012.

Several analysis and graphical functions allows for fast data analysis. The chromatic representation of the data allow for a fast understanding of the data over a period; in Figure 6 the columns represent the hours over a day, the lines represent each day of December 2012. The color of the boxes depends on the average value of the measured parameter in the respective time. It can be seen how by night the air quality increase in the periods in which the window is open.

Through information about lighting (natural or artificial lighting), CO_2 and volatile organic compounds (VOC) it becomes possible to extrapolate information about the presence of persons in the rooms Figure 7.

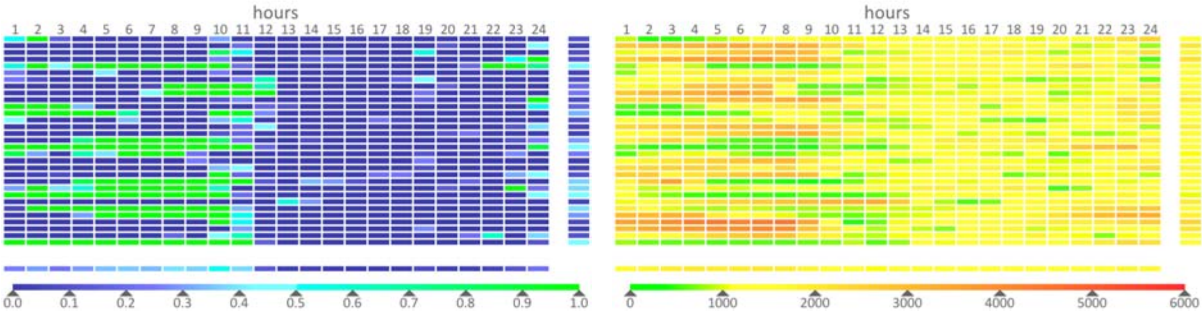

Figure 6. Chromatic representation of the measured variables. Left: Window opening time (0: Window closed, 1: window open for the whole hour). Right: CO2 average values in ppm. December 2012, a sleeping room of block 2.

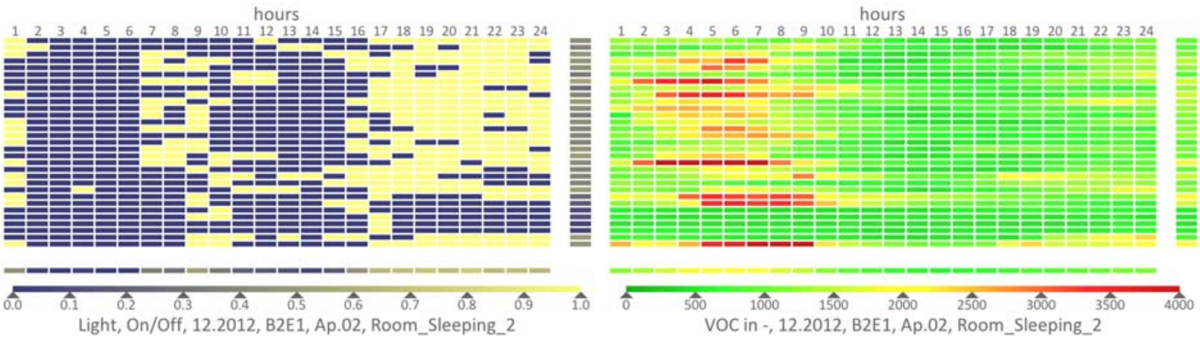

Figure 7. Chromatic representation of the measured variables. Left: light On/Off (0: no light was switched on during this hour, 1: light was on for at least one minute). Right: VOC average values. December 2012, a sleeping room of block 2.

Energy Demand of the buildings

A first comparison of the several refurbishment solutions has been done already before the refurbishment started, through energy demand values. Their primary energy demand has been calculated following the monthly balance procedure as described in the EnEV 2009 (based on DIN V 4701-10, 08.2003 [3] and DIN V 4108-6, 06.2003 [4]). The EnEV monthly balance procedure balances gains and losses of the building and its engineering system. The results presented in this paper are based on the following boundary conditions: Standard weather file for the region in which the buildings are located (Karlsruhe), internal gains set to 5 W/m²Floor Space, Air exchange rate set to 0.55/0.6 1/h (Depending on the kind of Ventilation system), average indoor temperature set to 19°C.

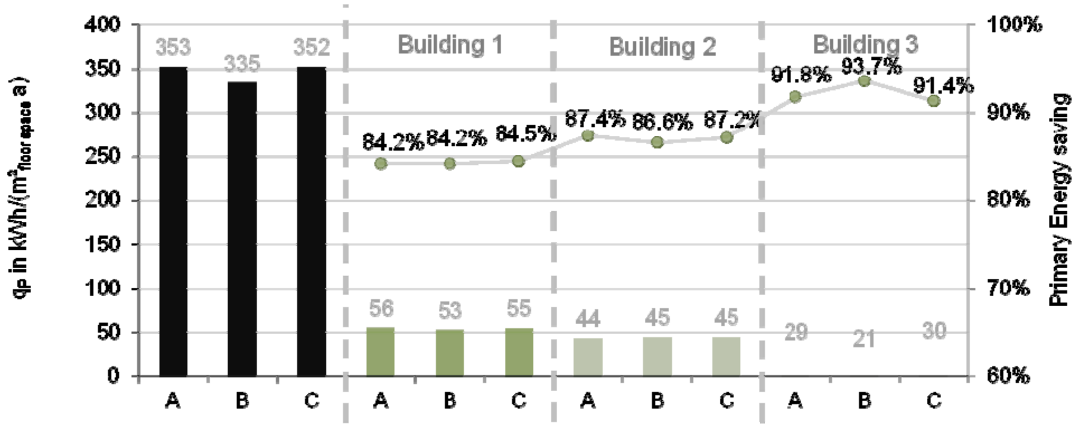

Figure 8. Primary Energy demand per square meter of floor space and year, of the buildings before and after refurbishment. In per cent, the primary energy saving of the retrofit solutions, compared to the primary energy demand of the buildings before the retrofit.

In this work, only the specific primary energy demand is presented and more details on the static calculations, primary energy balances and CO2 balances for this field test are presented in [5]. A comparison of the specific primary energy demand values before and after the refurbishment process, Figure 8 shows how big the potential of energy saving is for this three blocks (between 84% and 94%). Block 2 would save, compared to block 1, about 20% energy, block 3 around 50%.

The Energy Consumption of the blocks

The static balanced energy demand of a building is not a prevision of a future consumption, rather a way to evaluate a building under standard conditions in a particular climate. Static- balanced energy demand levels are used to compare buildings with different layouts, in terms of insulation and engineering system, between each other. Those values are also used to categorise buildings: this should on the one hand guarantee that new buildings respect energy savings laws, on the other hand help the user to buy or rent an object that results energetically convenient. Generally demand and consumption values may differ from each other due to several reasons: wrong parameters used for the calculations, mistakes in the installation of the engineering system, real user behaviour different from the assumed behaviour used for the calculation. In facts, persons interact with the building in many ways: E.g. through window opening, settings for the engineering system, use of the ventilation system and internal gains. This brings a discrepancy between static-balanced demand and real life consumption. Additionally, users may act differently with different buildings and/or engineering systems. Buildings heated by an outdated engineering system will usually be heated less than buildings with a high-tech engineering system. People tend to use new, efficient, goods (e.g. cars, lighting, cooling and heating systems, white goods) more than old inefficient goods. This effect is known as "Rebound Effect" [6] [7] [8].

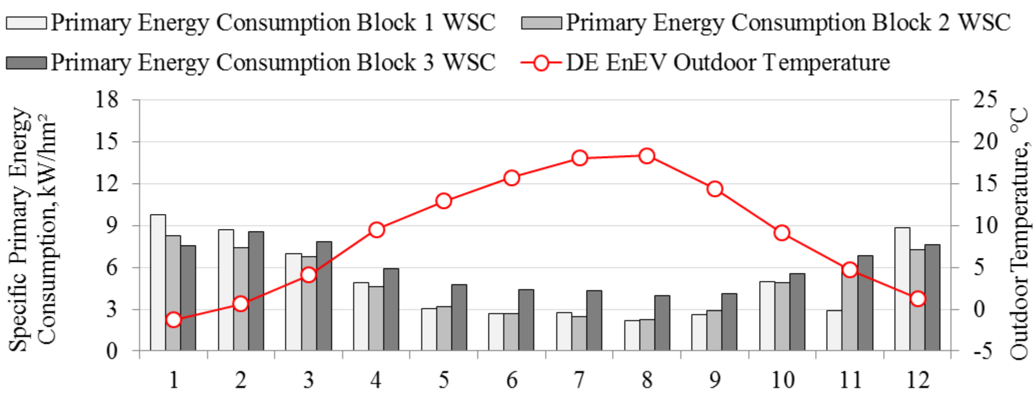

Figure 9. Weather season adjusted Primary Energy Consumption of the three buildings' blocks per month, after the refurbishment, year 2012.

The buildings, before the refurbishment process of 2008, were equipped (since 1980) with one gas boiler per apartment. The energy consumption values before the refurbishment process are directly comparable to the energy demand values, since the average temperature for Karlsruhe in this three year coincides with the average German temperature used for the calculation of the heating degree index of the EnEV (no weather seasonal adjustment needed). It has to be noticed that only gas consumption has been monitored before the refurbishment: for the primary energy consumption projection the auxiliary energy has been estimated in 6.5 kWh/(m²a) following the DIN V 4701-10, 08.2003 [3].

Between 2005 and 2007 the three blocks consumed in average 164 $kWh_{Primary\ Energy}/(m^2a)$. The EnEV energy demand of each block is 347 kWh/(m²a). With the demand calculation the consumption has been overestimated for more than 100%. In contrast to this, the demand values after the refurbishment process underestimated the real consumption (more details about consumption, demand and rebound effect found on this field test can be found in [9] and [10]).

In Figure 9 the primary energy consumption of the three blocks after the weather season adjustment process is shown. The outdoor temperature in the year 2012 in Karlsruhe (measured in the field test) was about 2K above German average outdoor temperature used in EnEV calculation. Hence, a weather season adjustment has been executed. The consumption of block 3 appears bigger than the consumption of block 1 and 2. This was caused by many technical problems that came out during 2011 and 2012 (broken heat pumps substituted by electrical heating system, wrong setting of the circulation pumps).

The Energy Consumption of each apartment

The user behavior plays a huge role in the final energy consumption for space heating and domestic hot water production. Comparing the consumptions of the several apartments, this becomes clearer.

	B2, Building 1		B2, Building 2		B2, Building 3	
5. F	6.4 22.9 9%	11.5 23.8 10%	2.8 21.2 30%	6.0 21.8 35%	4.3 22.8 5%	6.4 20.8 1%
4. F	2.5 22.4 28%	0.1 22.1 21%	3.6 22.7 33%	1.7 20.5 17%	4.9 22.6 34%	0.0 20.9 25%
3. F	7.1 22.7 31%	1.3 20.9 22%	8.1 22.5 16%	4.1 19.8 21%	11.7 22.3 42%	12.6 23.7 12%
2. F	1.3 21.3 29%	5.2 23.6 18%	3.9 23.6 1%	0.4 19.8 10%	1.6 21.5 16%	0.0 21.5 22%
1. F	1.7 20.2 8%	0.8 20.4 9%	0.5 22.0 30%	7.4 22.6 1%	0.7 21.0 36%	12.7 20.6 61%

Figure 10. Energy consumption (for space heating) of 30 apartments in December 2011. The value in the middle of each box indicates the energy consumption of the apartment in kWh/(m²a). The value on the left the average Temperature of the apartment, the value in % for how long have been the windows open, in average.

Figure 10 shows the average temperature, the average window opening time and the heating energy consumption of each apartment for December 2011. Beside the normal dependence between indoor temperature, window opening and energy consumption, it is interesting to see how "warm" apartment influence the temperature and the energy consumption of "cold" apartment. This phenomenon is very evident in this case and can be explained through the absence of any form from insulation between apartments (no inner wall insulation).

Also the domestic hot water consumption for the year 2011 reveals how differently can user act and hence influence the final energy consumption. The domestic hot water consumption for block 2 building 1 and block 3 building 1, 2 and 3 is shown in Figure 11.

Figure 12 shows the average heat load of three different apartments during December 2011, grouped depending on the ambient temperature. One user (W5) consumes a big amount of heating energy, and this amount strongly increase by colder temperatures. One user (W7) starts heating by colder ambient temperatures, his consumption depends on the ambient temperature. One user (W8) is almost not heating at all.

	B2, Building 1		B3, Building 1		B3, Building 2		B3, Building 3	
5. F	16.5	7.4	9.9	15.5	13.4	4.8	5.7	8.4
4. F	17.8	21.6		4.2	14.8		8.9	5.7
3. F	20.0	9.7	19.6	16.1	10.5	21.7	13.3	9.6
2. F	4.4	28.5	11.1	10.6	8.7	16.8	27.0	7.6
1. F	11.4	3.5	15.8	14.1	17.3	9.7	6.3	

Figure 11. Energy consumption of 40 apartments (block 2 building 1 and block 3 building 1, 2 and 3) in the year 2011 in kWh/(m²a). The gray are omitted due to failures in the measurement process.

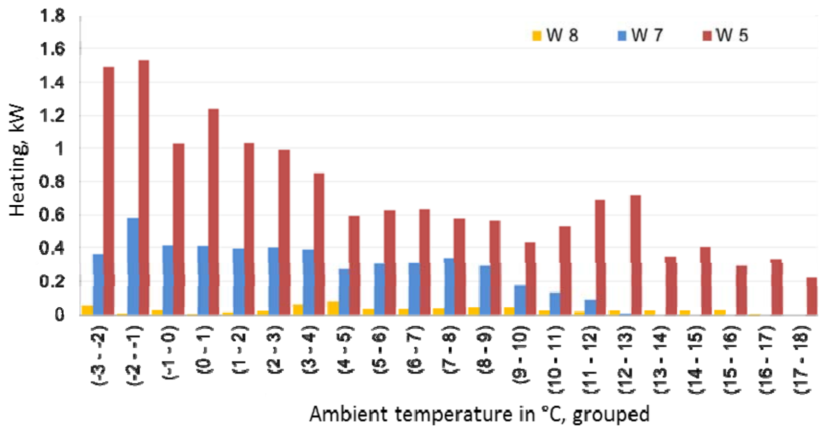

Figure 12. Average heat load value ambient temperature grouped per 1K.

Conclusions

The refurbishment process of nine buildings situated in a field test in Karlsruhe, Germany, has been described and evaluated in terms of consumption and demand values. It has been shown how demand (calculated EnEV 2009 values) and consumption (measured) values may differ. The central role of the user has been shown. In the next future the rebound effect will be in focus of the project. It will be analysed which technology may bring a bigger rebound effect compared to other.

In the near future more evaluation of the measured data will be executed. On one side it will be analysed which technologies may guarantee better comfort conditions (in terms of thermal comfort and air quality). On the other side it will be analysed which technology may bring a bigger rebound effect compared to other.

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Short Term Policy Strategies and Long Term Targets: The Case of the German Building Sector

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Abstract

The German government set targets for the reduction of heating energy demand in buildings (-20% of space heating energy need 2008-2020) as well as for the share of renewables in the overall heat sector (14% by 2020). In addition, long-term visions up to 2050 exist. The research questions of this paper are: (1) How can different policies affect space heating and hot water energy demand in Germany by 2020? (2) To which extent are these short-term policy interventions consistent with long-term targets? We use Invert/EE-Lab for modelling the German residential and non-residential building sector. The model takes into account barriers and investment decision patterns for the uptake of renovation measures and the investment in different types of heating, hot water and cooling technologies. More than 60 short-term scenarios until 2020 are simulated with different policy design options and energy price levels. They serve as a starting point for simulating a smaller number of scenarios until 2050. The short-term scenarios show that with ambitious policy design final energy demand in the German building sector for heating, hot water and cooling could decrease by about 16% from 2008 until 2020 (i.e. below 680 TWh in 2020 compared to 808 TWh in 2008), GHG-emissions could decrease by more than 50% and the renewable share could more than double. Though, this may seem promising, the long-term scenarios indicate that most of the short-term scenarios do not prepare the ground for really ambitious energy efficiency and climate mitigation targets of the building sector in 2050.

Introduction

The German government set targets for the reduction of heating energy demand in buildings (-20% of space heating energy need 2008-2020) as well as for the share of renewables in the overall heat sector, including space heating, hot water, industrial heat and cold (14% by 2020) [1]. In order to reach these targets tailor-made policies are necessary. In addition, long-term targets and visions up to 2050 exist both on the European and the national level.[2] However, it remains unclear to which extent the short-term policy strategies until 2020 are in line with the 2050 targets.

The core research questions of this paper are: (1) How can different policies affect space heating, hot water and space cooling energy demand and related CO_2-emissions in Germany by 2020? (2) To which extent are these short-term policy interventions consistent with long-term targets regarding energy demand and related CO_2-emissions?

For this purpose, we start with a description and detailed investigation of the current policy framework for heating and hot water in Germany and develop innovative policy sets as options for the short-term implementation. These policy sets are investigated by means of a techno-socio-economic bottom-up model (Invert/EE-Lab, described below), based on a detailed, disaggregated description of the building stock and related heating and hot water systems. This set of policy scenarios is the starting point of long-term scenarios until 2050. As a guideline for the development of these long-term scenarios we take into account storylines, combining the level of efficiency improvement on the building envelope on the one hand and the uptake of different heating and hot water systems on the other hand. By comparing the results from both scenario families we derive conclusions.

The results of this paper have been elaborated in the frame of the project "Integrated heating and cooling strategy for Germany", commissioned by the German ministry of environment (see e.g. [3] and [4]. This project covers the whole range of the heating and cooling sector, i.e. district heating and decentralized heating, space heating and cooling, domestic hot water and also process heat and cold.

For the long-term scenarios until 2050, the results presented in this paper will be updated until the project end in Autumn 2013. In this paper we focus on space heating and hot water. So, we explicitly excluded process heat and cold and also a closer investigation of district heating supply structure. Space heating and hot water preparation are covered in residential and non-residential buildings.

Methodology

We use the disaggregated bottom-up model Invert/EE-Lab for the description of the German building sector. The model takes into account stakeholder-specific barriers and investment decision patterns for the uptake of renovation measures and the investment in different type of heating, hot water and cooling technologies. Policies change the structure of this decision-making process in the model. Short-term scenarios until 2020 are simulated with different policy design options and energy price levels. We take these results as a starting point for simulating a smaller number of scenarios until 2050. The results of these long-term simulation runs in terms of energy demand, technology mix and GHG-emissions are compared to literature-based energy and climate targets for the building sector.

The model Invert/EE-Lab

Invert/EE-Lab simulates space heating, AC and hot water demand in a region's or country's building stock and for evaluating the effects of different promotion schemes and energy price settings on the energy carrier mix, CO_2 reduction and costs for RES-H support policies.

The Invert/EE-Lab simulation tool has originally been developed by Vienna University of Technology/EEG in the frame of the Altener project Invert [5]. During several projects and studies the model has been extended and applied to different countries within Europe, see e.g. [6], [7], [8], [9], [10], [11], [12]. The last modification of the model in the year 2010 included a re-programming process of the tool, in particular taking into account the heterogeneity of decision makers in the building sector and corresponding distributions [13], [14], [15].

Invert/EE-Lab in this paper is applied for Germany with the time horizon until 2050. However, recent and previous work also covered other countries and other time horizon (maximum until 2080). Currently, the model is extended for EU-28 (+Serbia) within the IEE project ENTRANZE (www.entranze.eu). The model is flexible regarding the number of heating and hot water technologies and the detailed definition of renovation measures to be considered in the scenario simulation.

The core of the tool is a myopical, cost-based logit approach, which optimizes objectives of agents under imperfect information conditions and by that represents the decision-making process concerning heating and hot water preparation. Invert/EE-Lab models the stock of buildings in a highly disaggregated manner.

For each year of the simulation period Invert/EE-Lab determines for each building segment the probability (expressed as share) that a building-related component (regarding building shell and heating / domestic hot water system) remains as it is and the probability (share) that one or more of these components are replaced. The share of buildings applying changes (measures) is calculated based on the age distribution of the considered building elements (facade, windows, heating and hot water systems, etc.) within the whole building stock using a Weibull distribution. The demolition of buildings is calculated in the same manner, yet considers life time expanding measures such as refurbishment in previous periods.

The share of the actual installation (market share) of available types is calculated based on adjusted heat generation costs using the logit approach, an approved and most widely used approach in the field of discrete choice theory (Train, 2003), where decision makers have to choose from mutually excluding alternatives. This approach has already been applied for modeling the heating sectors by other working groups (e.g. Giraudet et al. 2011; Henkel, 2010; Marnay and Stadler, 2008); their results indicate that this approach is also pertinent to our research questions. In principle, the applied logit model ensures that low-cost options, based on adjusted heat generation costs get the largest market share, but more expensive options hold some share, too.

Consideration of individual investment decision-making and investor-specific barriers

In Invert/EE-Lab the logit approach is extended by a few additional mechanisms like consideration of energy price development in recent years, an extension to a nested logit model, diffusion restrictions and other barriers. The agent-specific decision module allows a definition of different investor types and the simulation of investment decision making as a function of investor-specific variables reflecting barriers and perceptions. Figure 1 shows the structure of the module.

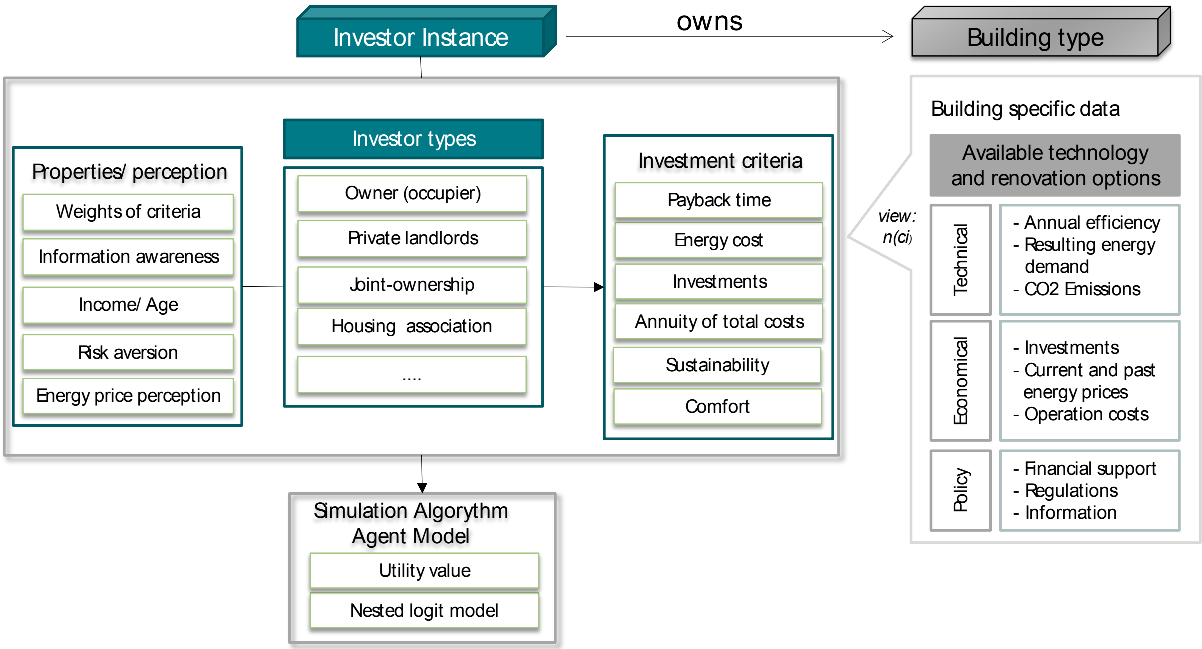

Figure 1: Overview of the agent-specific decision module

For detailed description of the methodology refer to [16]. The simulation of investment decision making in this model is based on different economic and non-economic criteria which are calculated subsequently for each combination of technologies, buildings and investor types. The defined properties of an investor determine how an investment decision is made (relevance of different criteria) as well as the perception of investment options and influencing parameters. The latter might result in different values of the decision criteria if the same technology is considered by different investors. For instance, dissimilarities of criteria values among investors can result from unequal knowledge of subsidy schemes and their consideration in the investment decision-making process. With respect to regulative policies such as minimum efficiency standards defined by building codes the model allows defining agent-specific compliance rates. The usage of the building by the investor is also considered as a parameter in the decision process. Thereby, the model differentiates between investors occupying the whole building, collective ownerships, private landlords and housing associations. Energy cost savings through an energy retrofit or a heating system change are only a relevant parameter for owner-occupiers, whereas the refinancing of an investment through additional rents is considered for private landlords and housing associations.

Using the investor-specific criteria values, total utility values for each technology options are calculated. Therefore, economic and non-economic values are normalised to utility values using a linear transformation. The total utility value of a technology option is determined using weights for each criterion which are defined individually for each investor type.

$$u_{ti} = \sum_{k=1}^{K} w_{ki} \cdot n(c_{kti})$$

u_{ti} : total utility value of technology t in choice set of investor i

w_{ki} : weight on criterion k set by investor i

$n(c_{kti})$: normalised value of criterion k for technology t in choice set of investor i

The result is a three dimensional matrix of utility values [technology options, building type x investor type] for each simulation year. [Steinbach 2013].

Typical investment behaviour of various agent groups is taken into account in the modelling approach. Thereby each agent is assigned with weighting factors for different decision parameters. These include total annual costs (annuity payment), amortization time, total investments, energy costs, comfort level as well as sustainability. The different agent types with their individual objectives and barriers are derived through a literature review, e.g. [17], [18] documented in [19]; [20].

Data sources

The German building stock is modelled on a highly disaggregated level. We distinguish five residential building categories (single-family houses, terraced houses as well as small, medium and large multi family houses) and 30 non-residential building categories (e.g. different private and public office buildings, shops, hospitals, schools etc.). For the residential sector we take into account 14 construction periods and different levels of previous renovation activities. For non-residential buildings, 3 construction periods are used, according to [21]. Combined with the different heating systems this results in a number of more than 4400 building segments.

To include these activities in the energy performance parameters the building stock in the base year 2008 was subdivided and U-values were adjusted for past renovation activity. To include the renovation information the building stock as laid out in the survey of [22] and updated in [23] was divided into 4 shares of different renovation levels according to their frequency. The first renovation level includes better energy performance parameters for one building component (e.g. windows). This is the most commonly renovated building part according to data interrogated in [24]. The second renovation level reflects the additional renovation of another building part, which is again identified by frequency of renovation in the survey data. Renovation levels three and four are determined in the same manner while the fifth share represents the buildings that were not renovated. The adjustment of the energy relevant parameters, i.e. the U-values of the building parts, was based on the renovation periods. For each period the most commonly used energy efficiency quality was assessed for the different building parts. The u-U-values for different renovation levels were subsequently adjusted to include a weighted average energy quality for the different renovation periods.

The main data source for the disaggregated description of the space heating and cooling demand in the non residential buildings in Germany is [21]. It is the follow-up of [25] and [26] each investigating the energy demand structure and developments in the German service sector based on bottom-up survey data. The innovative element in the 2011 survey was the integration of detailed questions regarding the energy demand for space heating and cooling. This led to the development of a buildings typology for the German service sector including the following main categories: type of building and use, size, age, specific demand as well as the number of buildings in each category. Data on the state of thermal insulation of the non-residential buildings is taken from [27].

In order to calibrate the model for the non-residential sector the bottom-up projections from [21] were compared to the German national energy statistics AGEB 2011. The comparison shows remarkable differences between the bottom-up and the top-down data for some energy carriers. The main reasons are: (1) a bottom-up projection based on a limited sample of data is characterized by a high level of uncertainty, (2) different assignment of technologies to energy carriers as is the case e.g. for small gas fired heating plants, (3) energy carriers that are not traded do not appear in the energy statistics while in the bottom-up projection they do, and (4) variations in the stocks of energy carriers influence the national energy balance while in the bottom-up survey they are out of the system boundaries.

The calibration of the model in the non-residential buildings sector furthermore led to the following findings: the heating demand of garages and storages calculated based on the national norms is much higher than in reality. On the one hand lower target temperatures are reached than foreseen by the calculations, and on the other hand only 30-50% (depending on the subsector) of the total floor area is fully conditioned.

Policy instruments

Existing policy instruments in the German building sector

Within the EU Germany is one of the few countries that have adopted long-term targets for the energy sector. In order to achieve a GHG reduction of at least 80% until 2050 (compared to the base year 1990) the building sector should become "nearly climate neutral" until the mid of this century. For the period until 2020 the sector's heat demand should be reduced by 20% compared to 2008 while the share of renewable energies in final energy consumption (space heating, cooling, process heat and hot water production) should be increased to 14% [28].

The building sector is addressed by various instruments. Sector-specific approaches include regulatory measures, especially the building code and the use obligation for renewable heating (RES-H); in addition financial support programs for new buildings, refurbishment measures as well as investments in RES-H in existing buildings.

The **building code** is set by the Energy Saving Ordinance (*Energieeinsparverordnung*, hereafter EnEV) which establishes minimum efficiency standards. For new buildings maximum building-specific levels of the primary energy demand and the required energy performance of the building envelope (expressed in maximum values of the specific transmission heat loss related to the heat transmitting surface area) apply.

Apart from the building code new buildings underlie a **use obligation for RES-H** which obliges building owners to cover a minimum share of their heating (incl. domestic warm water) and cooling demand by renewables (*Act on the Promotion of Renewable Energies in the Heat Sector*, hereafter EEWärmeG). For different technologies different minimum levels apply (for instance solar thermal 15%; biogas 30%; solid and liquid biomass, heat pumps 50%).

Substantial financial support is provided by two program lines: "Energy efficient construction" and "market incentive programme:
The programme "**Energy efficient construction**" is providing grants and tax-reduced loans to building owners of new buildings. Since the rate of construction of new buildings has been in the range of 1% in recent years the focus needs to be laid on the existing building stock, though. Here financial support is granted by the program "Energy efficient refurbishment". The support level is tiered according to the efficiency level a modernization measure is aiming at. The more ambitious the energy standard the higher the support equivalent. For the different support levels distinct efficiency levels (e.g. Efficiency House 55, 70, 85) have been established all exceeding the minimum requirements set by the EnEV.
The market penetration of RES-H installations in the building stock is supported by the **market incentive programme** (*Marktanreizprogramm*, hereafter MAP). Support is provided via grants (small scale installations) and soft loans (large scale installations). Similar to the EEWärmeG technology specific minimum requirements apply. The programme coverage is comprehensive, e.g. the majority of solar collectors that are installed on existing buildings are supported through the programme.

Apart from the sector-specific approaches there are a handful of cross-sectorial instruments that also have an impact on how the different actor groups behave in the sector. The most relevant instruments include:
- The **energy tax** that increases the end-consumer price of the main final energy carriers in the heating and cooling sector, namely natural gas, heating oil and electricity. In recent years the tax level was in the range of the typical market-induced price fluctuations of the respective energy carriers, though.
- The **Emissions Trading Scheme** (hereafter ETS) that has a direct impact on the price of electricity and district heat (provided the latter is generated in a power plant that underlies the ETS).
- The **European Ecodesign requirements** that define minimum efficiency standards for the most relevant technologies in the heating sector (e.g. boilers, warm water generators, pumps), and the energy labelling requirements for such devices, respectively.
- **Regulations specifically addressing CHP** (especially providing financial support).
- Furthermore, there are programmes that aim at **increasing the information and motivation level** of the different decision-making groups in the heating and cooling sector as well as training and education of those who produce, trade, sell, purchase, operate and maintain the respective efficiency and renewable energy technologies, and those who provide advice. Finally, specific laws regulate the

relationship between landlord and tenant (e.g. toleration and cost allocation rules) or under which framework conditions refurbishment decisions need to be taken in the case of joint ownership (owner occupancy in multi-family buildings).

Development of innovative policy settings

In order to achieve the targets for the building sector the policy framework needs to be further developed. This is of particular importance in view of the long-term targets. Due to the rather long re-investment cycles in the building sector especially for the major structural components of a building, todays modernization standards will to a certain extent already determine the GHG level in 2050.

For that reason different policies and policy combinations are modelled that change the framework conditions in the building sector. In addition to several cross-sectorial instruments target group, sector and technology specific have been taken into account. The list of modelled measures includes instruments that are currently on the political agenda [28], approaches that proved to be successful in other countries as well as measures proposed by the authors. Several measures have been combined to jointly build policy bundles. The rationale behind policy bundles lies in the experience that many energy saving potentials in the building sector aren't hampered by only one isolated barrier but rather a multitude of simultaneous barriers. Moreover, different target groups, e.g. homeowners of single-family houses, actors in the rental housing sector, homeowner associations, low-income homeowners, often have rather target group-specific barriers [29], [20]. This implies the need of policy bundles that include different, partly rather target-group specific measures as to address various barriers simultaneously.

Policy bundles have been developed alongside different policy lines. The following bundles have been modelled:

I. Focus on regulatory measures.

II. Focus on financial support instruments financed through public budgets.

III. Focus on financial support instruments financed independently from public budgets (or at least budget-neutral counter-financing by raising additional revenues to the public budgets).

IV. Ambitious and target group-oriented measures.

The bundles combine instruments of different design (see table 1). In addition, all bundles involve a number of measures aiming at improving quality and quality assurance, information, motivation and advice as well as training.

Short-term policy scenarios up to 2020

For the analysis we developed a total of more than 60 scenarios grouped in three scenario families and two energy price scenarios (high price according to [30] vs. low price according to [31]): (1) “hesitant consensus” describes a future without clear climate mitigation targets and without effective policies. (2) “Two tempi” shows quite ambitious targets and effective policy measures in Germany. However, due to a lack of global consensus, technological development is slow and diffusion constraints can be overcome only partly. (3) Under “global consensus” favourable conditions lead to an environment where barriers can largely be removed and technological development allows a faster diffusion of RES-H and renovation technologies. The title of this scenario family suggests that these favourable conditions could be created in particular under a regime of worldwide consensus for ambitious climate targets and effective policies.

Table 2 shows the simulations and setting of policy packages in the different scenario families. Under “hesitant consensus”, we simulated a “frozen policy” scenario. This frozen policy scenario assumes no further development of the policy framework for RES-H and building renovation after 2011. Under “two tempi” and “global consensus” we simulated different settings of policy packages as described above. For the purpose of this paper we want to derive conclusions regarding the requirements of short-term policy making compared to long-term targets. Therefore, a focus on the more ambitious scenarios is relevant. Consequently, in the following we will present results for the scenario “frozen policy” and contrast them with several scenarios from the high-price “global consensus” scenario family.

Table 1: Main components of four different policy bundles

	I	II	III	IV
New buildings	Gradual tightening of the building code until 2020 (objective: nearly zero energy standard) EEWärmeG: no substantial changes			
	KfW “Energy efficient construction”: Freezing of the available funds			redirecting the funds for new buildings to refurbishments
Existing buildings	Tightening of the refurbishment standards either once or twice by 30% each time. Improving compliance of these standards. EEWärmeG: Extension of the RES-H use obligation to existing buildings (trigger: boiler replacement).	KfW “Energy efficient refurbishment”: Increasing available funds Introduction of tax incentives for refurbishment measures MAP: Increasing available funds	KfW “Energy efficient refurbishment”: Increasing available funds by implementing a budget neutral financing mechanism (surcharge on energy tax) Replacing the MAP by a budget independent quota or premium scheme for RES-H	Tightening of the refurbishment standards either one off or two times by 30% each time. Improving compliance of these standards Replacing the MAP by a budget-independent quota or premium scheme for RES-H A range of target group-specific measures (incl. target group-specific financial support) for private small scale owners (self-occupancy and tenure), ownership associations, commercial owners and public buildings

Table 2: . Clustering of simulated policy packages

			Focus subsidies		
	Frozen Policy	Focus regulatory measures	through public budget	Independent of public budget	Ambitious and target group-oriented measures
Hesitant consensus	X				
Two tempi		X*	X*	X*	X
Global consensus		X	X	X	X

(*) … without very ambitious measures

Table 3 shows the key results for selected scenarios in the year 2020. Compared to the base year 2020 the total final energy demand could be reduced by 13-16%, the share of RES-H could be increased to about 15-23%. The high share of RES-H in 2020 is a result of an ambitious mix of strong regulatory measures (RES-H use obligation coming into effect in case of heating system change), economic incentives and various target-oriented measures (see above).

Table 3: . Key scenario results in the year 2020 in the short-term scenarios

		Reduction in … (a)		Share of …						
		Total final energy demand	decentralised fossil energy demand	RES-H	Biomass (c)	ambient energy	solar thermal	district heating	Electricity (b)	fossil
	Frozen-Pol hp	13%	22%	15%	12%	1%	1%	14%	4%	68%
Regulatory measures	Energy saving enforcement once	15%	26%	16%	13%	1%	2%	14%	4%	66%
	Energy saving enforcement twice	16%	26%	16%	12%	1%	1%	14%	4%	67%
	Energy saving enforcement twice + use obligation for RES-H heating system change	16%	32%	18%	15%	2%	2%	15%	5%	62%
independent from public budget: premium		14%	23%	15%	13%	1%	1%	13%	4%	67%
through public budget	Subsidies RESH	15%	25%	16%	13%	1%	1%	13%	4%	67%
	Subsidies RES-H + renovation	15%	24%	16%	13%	1%	1%	13%	4%	67%
Ambitious and target group-oriented measures	Renovation + premium	16%	29%	17%	14%	1%	2%	14%	4%	64%
	Renovation + Premium + use obligation for RES-H heating system change	16%	38%	23%	18%	2%	2%	16%	6%	56%

(a) reduction refers to the reference year 2008
(b) electricity includes auxiliary energy, electricity for heat pumps, direct electric heating and hot water
(c) includes decentralised biomass and small biomass district heating (below 2 MW). Biomass in large district heating is not covered here but included in the column “district heating”

Long-term policy scenarios until 2050

Long-term policy visions and targets for the building sector

A number of scenarios illustrate how the building sector could look like assuming the long-term climate targets are met (e.g. [31], [32], [30]). The scenarios coherently highlight the importance of the sector to reach a GHG reduction target exceeding 80%. The scenarios are rather heterogeneous about how the building sector will look like in detail. For instance, in [31] the specific average space heating energy need of the residential building stock decreases until 2050 to around 22% of the average value in 2008 (excluding domestic warm water). With a reduction of 85% (compared to 2005) in [32] the cut is even higher. In both scenarios the specific demand of the 2050 average building stock is considerably lower than of average new buildings built today. The remaining heat demand is mainly covered by renewables making the sector almost climate-neutral in the long term. In [30] the average specific space heating demand is lowered “only” by 57%. Compared to the other two scenarios insulation measures reducing the heat demand in [30] are partly compensated by a larger volume of renewables entering the sector.

Based on this background we formulated different storylines for the future long-term development of the building sector, which all have to be in agreement with the long-term political goals and which are mainly characterized by the following attributes: development of living area; development of electricity consumption; level and extent of energy retrofit of the existing building stock including replacement of buildings by new ones; fraction of the building sector covered by district heat; mix of used heating technologies with a particular focus on the extent of using electric heat pumps, and finally the form and amount of biomass used in the building sector. Six possible developments - storylines – were formulated which are characterized by different compositions of the extent of change of these attributes:

1. Electricity-dominated building sector with strong increase of efficiency: here only moderate construction of new district heating networks will take place and biomass will not be a major energy source for the building sector, but electrically driven heat pumps will play an important role.

2. Electricity-dominated building sector with a low increase of efficiency: similar to the first one, but much more renewables will be needed in order to cover the higher remaining energy demand for space heating.

3. Building sector with a strong increase of district heating networks and with a strong increase of efficiency: district heating networks will play an important role in particular in urban areas and as such provide means for energy management on a city or district level.

4. Building sector with a strong increase of district heating networks and with a low increase of efficiency: similar to the system above district heating networks are important but a large of biomass will be needed in the building sector in order to fulfil the long-term political goals.

5. Building sector with a moderate increase of district heating networks and with a strong increase of efficiency: in such system a mix of all measures – efficiency, use of electric heat pumps, increased employment of district heating networks - will take place.

6. Building sector with a moderate increase of district heating networks and with a low increase of efficiency: in contrast to the storyline No 3 a large amount of biomass will be needed in the building sector in order to fulfil the long-term political goals.

Simulation results

Based on these key ideas of storylines, we carried out model-based simulation runs. All these model runs are ambitious scenarios in the sense that a strong reduction in fossil energy consumption and related CO_2-emissions is achieved. However, the way how this target is achieved is different in the scenarios.

For the model implementation of the storylines outlined above we made the following assumptions:

In the efficient scenarios we assumed that from 2015 on only high quality and deep renovation activities take place. This would imply that all renovation activities are carried out in the quality of the current “KfW55-standard”. This would require a very strong regulative approach, combined with corresponding measures of training, quality assurance etc.

In the “less efficient” scenarios, from 2035 on, there is an obligation to carry out thermal renovation activities. Pure maintenance measures like painting the façade or the windows are not allowed anymore. In case that some refurbishment activity is set on some component of the building, a full renovation of the whole building has to be done. The financial support is the same as currently implemented in the German policy set.

The energy potential of district heating in 2050 is reduced to 50% compared to the base year in the “electricity-based scenarios”. In the remaining scenarios there is no restriction.

For all scenarios a RES-H use obligation was implemented. Until 2020 it applies to all buildings fndergoing a major renovation. From 2020 on it is applied to all buildings changing the heating system. This instrument is a major driver for take-up of non-fossil heating systems in all scenarios. Financial support (investment subsidies) for RES-H systems is implemented in all scenarios, however with different intensity: in the electricity-based scenarios no subsidies for biomass are granted, and slightly higher support levels for heat pumps are granted compared to the other scenarios.

In the electricity-based scenarios we assumed coupling between the electricity and the heating sector in the form that heat pumps are incentivised by lower electricity prices due to their potential to shift the load to periods with high generation of volatile renewable electricity.

The potential of biomass for heating purposes has been reduced in the electricity-based scenarios. In the other scenarios, the potential for decentralised biomass has been reduced as well. However, due to the growth of small biomass district heating, the overall amount of biomass in the heating sector slightly increases.

Figure 2 shows the final energy demand by energy carrier for two exemplary cases: the scenarios “1 electric efficient” and “2 electric less efficient”. Considerable progress is achieved in both scenarios and the reduction of fossil energy carriers is very similar. However, in the second case of lower energy efficiency higher electricity consumption and additional effort in exploiting renewable energy are required.

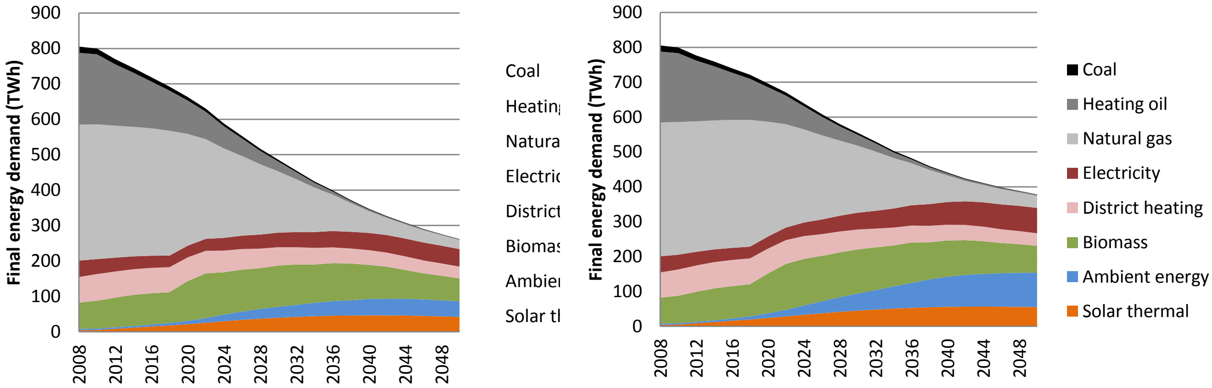

Figure 2: Final energy demand for space heating and hot water by energy carriers in the scenario “1 electric efficient” (left) and in the scenario “2 electric less efficient” (right) until 2050

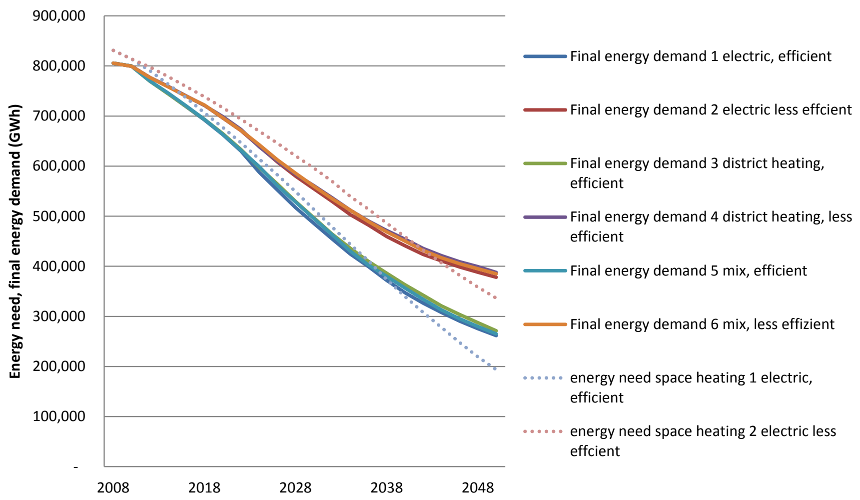

Figure 3: Energy need for space heating and total final energy demand for heating and hot water preparation in different scenarios until 2050, Germany

Energy need for space heating refers to the theoretical calculation of energy need, without taking into account rebound effects and user behaviour. Final energy demand takes into account user behaviour and rebound effect.

Table 4: . Key scenario results in the year 2050 in the long-term scenarios

	Reduction in … [a]		Share of …						
	Total final energy demand	decentralised fossil energy demand	RES-H	Biomass [c]	ambient energy	solar thermal	district heating	Electricity [b]	fossil
1 electric, efficient	68%	95%	58%	25%	17%	16%	19%	19%	11%
2 electric, less efficient	61%	94%	74%	25%	14%	18%	18%	23%	12%
3 district heating, efficient	66%	96%	63%	37%	12%	14%	29%	15%	9%
4 district heating, less efficient	52%	95%	64%	32%	20%	13%	26%	16%	8%
5 mix, efficient	67%	96%	61%	32%	13%	15%	23%	17%	10%
6 mix, less efficient	52%	95%	63%	27%	21%	14%	19%	13%	7%

(a) reduction refers to the reference year 2008
(b) electricity includes auxiliary energy, electricity for heat pumps, direct electric heating and hot water preparation
(c) includes decentralised biomass and small biomass district heating (below 2 MW). Biomass in large district heating is not covered here, but included in the column "district heating"

Table 5:. Key scenario results in the year 2020 in the long-term scenarios

	Reduction in … [a]		Share of …						
	Total final energy demand	decentralised fossil energy demand	RES-H	Biomass [c]	ambient energy	solar thermal	district heating	Electricity [b]	fossil
1 electric, efficient	18%	31%	21%	17%	1%	3%	14%	5%	64%
2 electric, less efficient	14%	28%	22%	16%	1%	3%	13%	5%	64%
3 district heating, efficient	17%	31%	22%	18%	1%	3%	16%	5%	63%
4 district heating, less efficient	13%	28%	23%	18%	1%	3%	16%	5%	62%
5 mix, efficient	18%	31%	22%	17%	1%	3%	15%	5%	63%
6 mix, less efficient	14%	31%	22%	17%	2%	3%	14%	5%	61%

(a) reduction refers to the reference year 2008
(b) electricity includes auxiliary energy, electricity for heat pumps, direct electric heating and hot water preparation
(c) includes decentralised biomass and small biomass district heating (below 2 MW). Biomass in large district heating is not covered here, but included in the column "district heating"

Figure 3 shows that the energy need for space heating can be reduced significantly, to 23% and 40% in the "efficient" and in the "less efficient" scenarios, respectively. This refers to a reduction in final energy demand to about 32% (scenario 1 electric, efficient) and 48% (scenarios 4 and 6). The total amount and shape of the reduction curve of energy need and final energy demand are different. This has several reasons: (1) The replacement of outdated, low efficient heating systems by modern, efficient heating systems tackles a substantial potential for efficiency improvement. This potential is exploited around 2030 due to the lifetime of the heating systems. (2) There is a considerable rebound effect to be considered for thermal renovation measures. With stronger diffusion of thermal renovation the rebound effect compensates a larger and larger share of the theoretical energy savings (depicted in the graph as the energy need for space heating). (3) Building renovation and the related reduction of space heating energy need does not automatically lead to a reduction in energy need for hot water. Overall, the rebound effect compensates for the efficiency gains in the heating system.

The final energy demand (including solar thermal energy and ambient energy) is very similar in all "efficient" scenarios on the one hand and the "less efficient" scenarios on the other hand. Also, all scenarios show a strong increase of RES-H from about 10% in the base year (2008) up to the range of 58%-64% in 2050. The reduction in decentralised fossil energy demand in all scenarios is about 95% in 2050.

However, the mix of different RES-H technologies and energy carriers varies strongly. Table 4 shows the share of different RES-H technologies in 2050 for the different scenarios. The restriction of the biomass resource potentials leads to the lowest share of biomass in the electricity-based scenarios. This drives the uptake of heat pumps and solar thermal systems. Scenarios 4 and 6 lead to the highest share of ambient energy without a significantly higher electricity demand. This can be explained by the higher uptake of low-efficient air-source heat pumps in the "efficient" scenarios: in better insulated buildings high investments in efficient technologies do not pay off and therefore consumers tend to heating systems with lower investment, even with lower efficiency, if there are no additional efficiency standards and requirements in place (which we did not take into account).

Conclusions and discussion of open questions

Conclusions regarding 2020 scenarios

Measures for thermal renovation have only moderate effect until 2020 due to the long lifetime of building components and corresponding inertia. However, the stronger enforcement of building regulation shows effect also in the short-term. Higher economic incentives for thermal building renovation also show short-term effect. However, this would only be the case if high additional public budget is available for these measures (in the range of about 5 billion Euro).

Those packages which combine different regulatory measures and economic incentives with target oriented measures as well as training, education, and promotion activities show the highest impact. In particular this also includes a change of tenant's laws, improved quality standard and higher compliance with standards.

The strongest diffusion of RES-H can be achieved with policy packages including use obligations coming into effect in case of heating system change. An improvement of financial incentives alone (investment subsidies) is not enough to reach the overall target of a RES-H share of 14% in the overall heating sector (which would require a share of at least 17-18% in the building sector).

Policy instruments financed independently from public budget by corresponding levies on fossil fuels may lead to a similar impact as current subsidy programs. However, a much lower amount of public budget would be required and a higher transparency and stability of the program could be achieved.

Conclusions regarding 2050 scenarios and the comparison with short-term scenario results

The competition for biomass for different purposes (energy and non-energy) is likely to become more and more severe. From an exergetic point of view, the use of biomass for providing low-temperature heat is not efficient. With an increasing decarbonisation of the space heating and hot water sector the availability of biomass for heating purposes becomes an increasingly crucial issue. The scenarios show that the restriction of biomass availability substantially drives the demand for other RES-H systems, in particular heat pumps but also solar thermal and district heating.

The most efficient short-term scenarios almost achieve the same values as the "efficient" long-term scenarios in the year 2020. The low-efficient short-term scenarios are quite far off from the efficient long-term scenarios. However, even the low-efficient 2020 scenarios (like the frozen policy scenario) are in a similar range as the "less-efficient" 2050 scenarios. This leads to some relevant conclusions:

It is possible to compensate lower efficiency of buildings with a higher share of RES-H. However, this puts pressure on the exploitation of renewable energy sources with corresponding social, ecological and economic consequences (see the discussion point regarding biomass potentials above).

The building stock has a high inertia and long lead-times. This leads to the conclusion that early action is required. On the other hand, it also means that lock-in effects have to be avoided. If they are not compatible with long-term targets early actions might counteract long-term ambitious targets. So, it might be reasonable to favour high quality renovations in the next years instead of aiming at increasing the renovation rate (while accepting low renovation standards). At least, all renovation activities should be designed in a way not to hinder later deep renovation activities.

Thus, in the design of short-term policies the focus should not necessarily be put on achieving high energy savings in the short-term. Rather, the required steps for medium and long-term high energy savings standards should be put forward. This may include high standards in building codes and energy efficiency of equipment, high efforts in increasing the quality by training, qualification, education and technology development. In general, a stronger focus should be put on high quality and deep renovation activities than on a high rate of renovation without high quality potentially leading to lock-in effects.

All long-term scenarios achieve a high RES-H share already in the short-term. This is due to the implemented policy settings (RES-H use obligation). Other policy sets could be investigated in further analyses.

Open questions:

The analysis in this paper opens up a long list of important additional questions, which should be addressed in further research, e.g. the following: Due to the increasing role of district heating, at least in some scenarios, the supply mix of district heating is a relevant issue for the overall assessment of the scenarios. This has to be investigated in further analyses. The same holds true for the mix of electricity generation. It is reasonable to assume that a high level of decarbonisation may be achieved in Germany. However, the marginal additional consumption of electricity, in particular during winter times, might nevertheless be covered by fossil peak load power plants. This should be taken into account in a comprehensive assessment. In particular this leads to the question of the potential of RES-E generation. An in-depth coupled investigation of heating and electricity sector would therefore be relevant to answer these questions. In the further progress of the project “heating and cooling strategy 2050”, some of these questions will be addressed. Some aspects of technological learning and potential new technologies could affect the results of this paper. In particular thermal storage technologies could increase the potential of solar thermal and of combined heat pump – solar thermal systems.

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IMPACT ON ENERGY CONSUMPTION OF A HOME AUTOMATION SYSTEM. A CASE STUDY

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INTRODUCTION

This case study refers to an existing flat purchased by a young couple and requiring a partial renovation. The flat is located in Pavia (Lombardy, Italy) and has a floor area of approximately 100 m2.

The flat and the consumer behaviour can be considered typical of the North of Italy. The main characteristics of the installation are the following ones:

1. heat generator (for water and space heating): wall mounted natural gas 24 kW boiler with hydronic radiators
2. cold generator: electrical AC 2,7 kW
3. lighting installation: fourteen lighting points and nineteen control points
4. seven blinds

Before renovation, on the basis of energy bills the energy consumption per year can be estimated:

1. for heating as 10,776 kWh
2. for summer cooling as 656 kWh
3. for lighting as approximately 328 kWh.

The case study compares three different home automation solutions and for each one of them evaluates the impact on energy savings.

The three solutions are compared on the basis of the document EN 15232. The paper provides also an economic cost/benefit analysis with reference to national energy and installation costs.

The initial higher cost of original equipment due to the inclusion of home automation devices and systems is evaluated together with the payback time and the internal rate of return in comparisons with energy savings from the three different solutions.

EX ANTE SITUATION

The flat is located in Pavia (Lombardy, Italy) and has a floor area of approximately 100 m2. It is a good example for home automation application.

The architectural layout of the flat is represented in Figure 1.

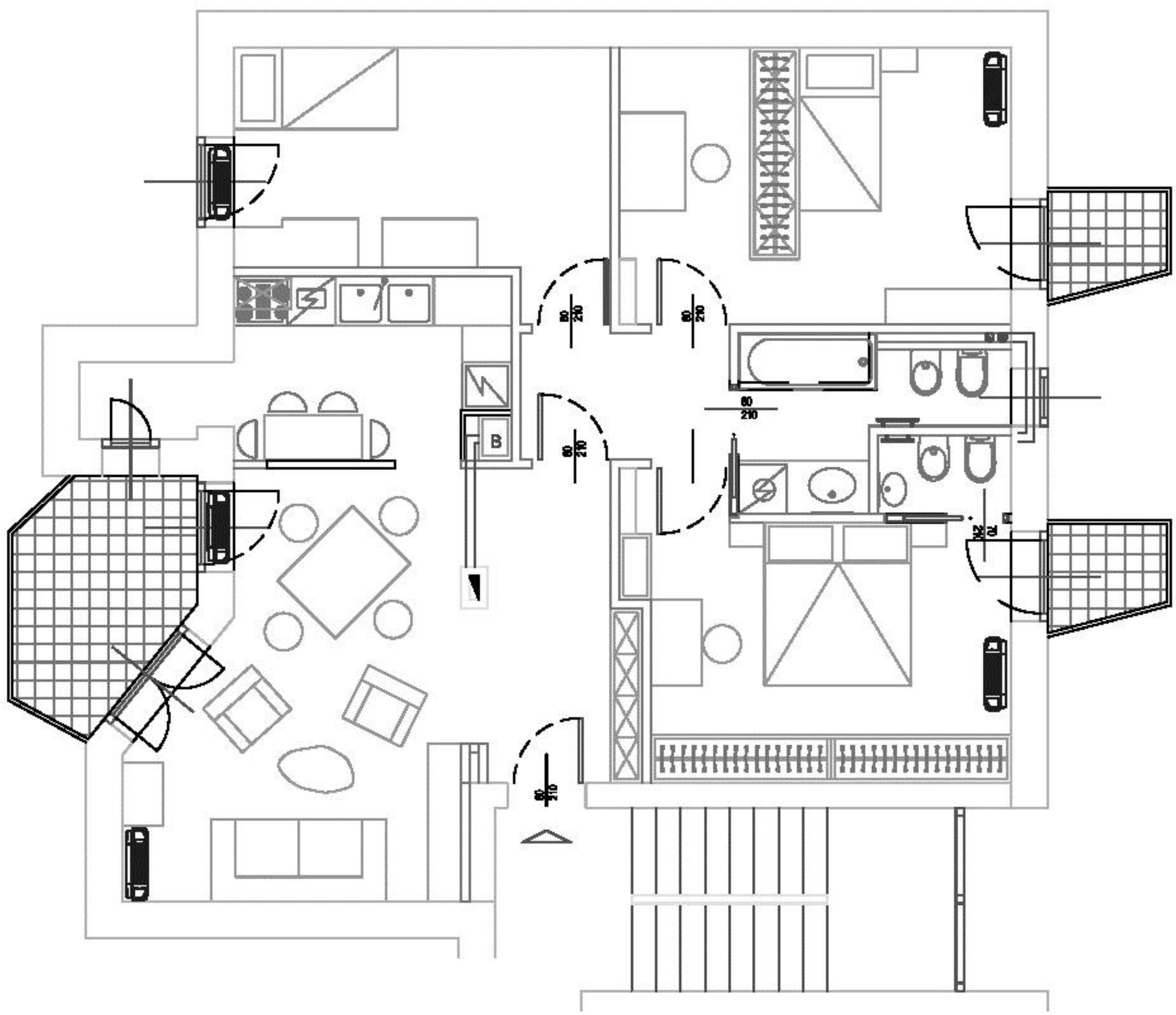

Figure 1 - Flat layout – Source: ECD archive www.ecd.it (architectural design Studio BP)

The flat is composed by the following rooms:

1. Entrance hall, living room and kitchen;
2. Hallways;
3. Bathroom and toilet;
4. Double bedroom with ensuite toilet;
5. Two single bedrooms.

Installation to be managed

HVAC

The heating system terminals are fan-coils.

The heat generator (a wall mounted natural gas 24 kW boiler) heats the thermal fluid (water) allowing, through the distribution network (manifold and pipes), the circulation of the fluid to reach the terminals for heating the environment.

During summer the fan-coil system makes cools of the flat by circulating chilled water to the radiators.

The young couple has expressed a desire to have an automatic ventilation system, to ensure the exchange of air between the flat and the outdoor, and to avoid manually opening and closing doors and windows.

Consumptions

Before renovation, on the basis of energy bills the energy consumption for heating were 10,776 kWh per year (3 years average), while summer cooling consumption per year amounts to 656 kWh (including consumption of auxiliary equipment required for air-conditioning throughout the year).

Table 1 – Boiler technical data

Heat input max	25,8 kW
Heat output in central max	23,5 kW
heating operation min	7 kW
Efficiency Pmax (80-60°C)	91 %
Nox emission class 3	3
Central heating operating pressure max	3 bar
Central heating operating pressure min	0,8 bar
Central heating temperature max	90 °C
Central heating water content	1 l
Central heating expansion vessel capacity	8 l
CH expansion vessel pre-charge pressure	1 bar
Index of protection IP	X5D
Power supply voltage	230 V/50 Hz
Power input	80 W

Table 2 – Fan coils technical data

Power Supply Cooling Capacity	2700 W
Heating Capacity	4500 W
Air Volume	510 m3/h
Water Volume	0,52 m3/h
Rated Input Power	30 W
Rated Input Current	0,14 A
Water Pressur	14 kPa
Max Noise	39 dB(A)
Net Weight	11,2 kg
Net Dimension	795*285*215 mm

Ligthting

The ligthing installation consists of fourteen lighting points and nineteen control points, as shown in Figure 2.

Table 3 – Lighting system composition

50 W halogen bulbs	6
20 W halogen bulbs	12
16 W CFL	8

Consumptions

Before renovation, on the basis of energy bills the energy consumption for lighting has been estimated as approximately 328 kWh.

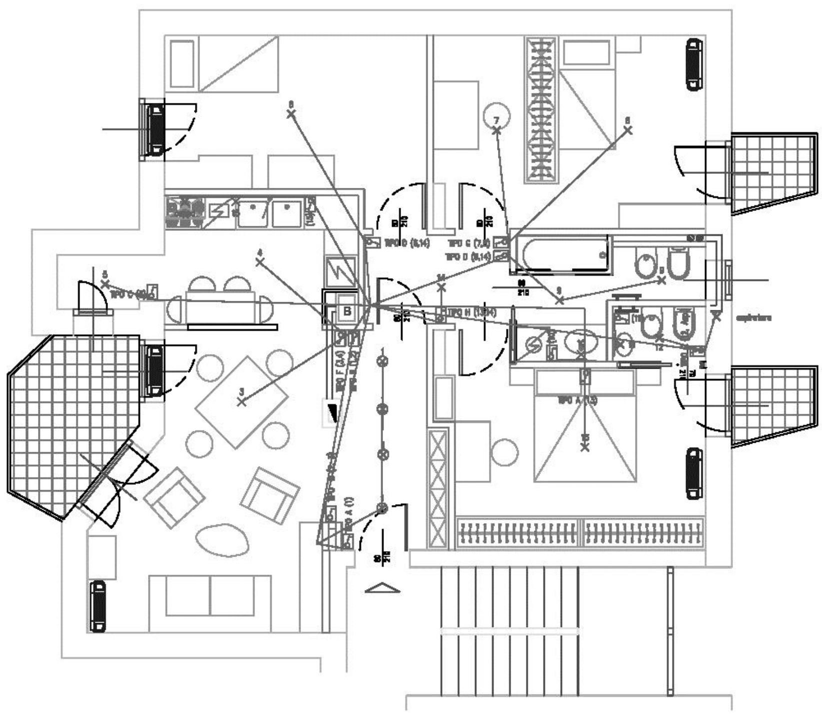

Figure 2 - Flat layout with lighting installation – Source: ECD archive www.ecd.it

Blinds

Before renovation the flat had seven blinds, five of them driven by a user-activated motor.

Consumption of systems and equipment

Figure 3 shows an estimate breakdown of historical energy consumption, which totalled 16242 kWh/yr. The major energy consumer is the heating system.

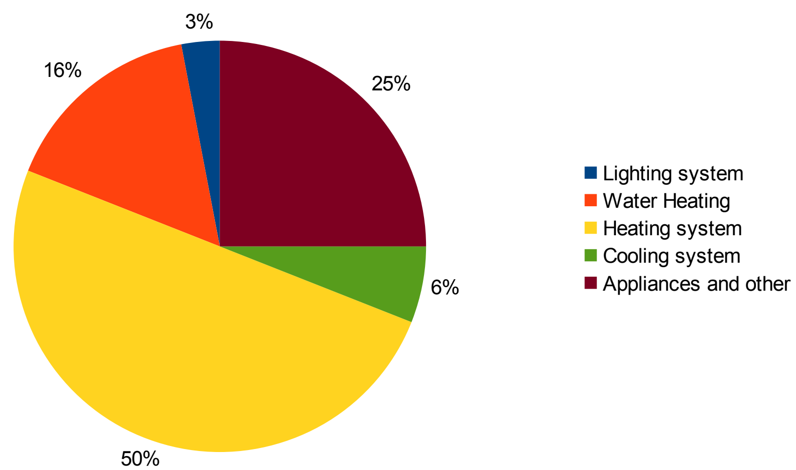

Figure 3 – Energy consumption by equipment and system (statistical evaluation).

Table 4 - Energy consumption by equipment and system (historical evaluation).

Lighting	3,00%	328 kWh
Water Heating (gas)	16,00%	1749 kWh
Space Heating (gas)	50,00%	10776 kWh
Cooling	6,00%	656 kWh
Appliances and other (elect. and gas)	25,00%	2733 kWh
Total (gas)	**66,00%**	**12.525 kWh**
Total (electricity)	**34,00%**	**3.717 kWh**
Total (all)	**100,00%**	**16242 kWh**

DESIGN SOLUTIONS

Before the renovation, the designer proposed three alternative solutions characterised with three different levels of automation as defined in the standard EN15232:

1. solution # 1: corresponding to the high energy-efficient class (Class A)
2. solution # 2: advanced energy efficiency (class B)
3. solution # 3: standard energy efficiency (class C).

The automation options considered were: automatic motor-driven blinds and lighing sensors, to manage the contribution of solar radiation, for optimum balance of solar heat and light.

The light control points in the kitchen and on the mirrors in the toilets were not connected to the bus in any design solutions. The number of control points and light points are unchanged, so it has not been taken into account in the estimation of the cost.

The costs and savings from these options were calculated, and presented to the clients for their decision.

Solution #1 (Class A)

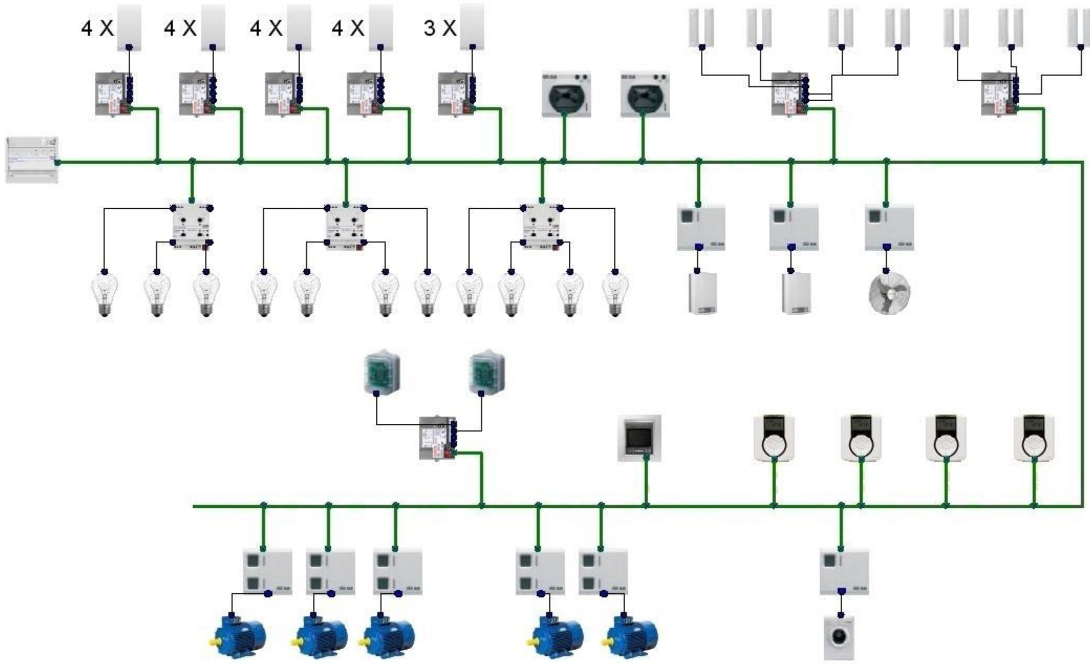

Figure 4 – Indicative scheme of the BUS of solution #1

Solution#1 includes two fully automated occupancy sensors: the first one for entrance hall and the living room and the second one for the corridor.

In these two environments the switching on and off of lights are automated depending on the passage of people.

Communicating by way of the wired bus system, a control panel allows the control through a suitable adjustment of heat and cold generator that feed the fan coil terminals. By regulating the climate of the whole living environment consumptions are optimized. In fact the temperature in every room of the flat can be controlled independently, and each terminal can also be scheduled to avoid unnecessary losses of energy during periods when the relevant rooms are not occupied.

Control of blinds (shading) is motorized and automatically driven by two light sensors depending on external lighting, which open them to maximize the free energy contribution of solar radiation in winter, or (in the rooms not occupied) close them during summer to avoid the sun's heat load (which would increase consumption for cooling).

It is also possible to schedule all blinds to close during the night for security reasons and to reduce heat loss both winter and heat gain in summer.

The motors driving the blinds are not additional costs because they were already existing; but new drivers and sensors were necessary.

Each of the seven windows of the flat is equipped with a radio frequency magnetic contacts that communicate with the system bus to indicate whether the window is open or closed, so the control system can turn off local terminals in order to avoid thermal energy losses.

The ventilation system, based on a single fan installed in the ceiling, allows the automatic change of the air in each of the five rooms. The air exchange system is regulated and programmable by the control panel and controlled via the system bus.

The electricity price is based on twin rates, and . before the renovation, energy use during the higher cost period led to high charges for electricity consumption.

The home automation system, through the control panel will allow the easy programming of appliances (like washing machine and dishwasher) to operate at night and on weekends, when the specific cost of electricity is lower.

Two channels, respectively connected to the washing machine and dishwasher, getting the signal from the bus system, allow the use of these appliances in fully automatic mode.

Solution #1 will allow the owners to move approx 90% of the electricity consumption in lower cost bands.

Finally, always through the control panel, users can manage two simple scenarios contributing significantly to energy savings and security. The first scenario is the central locking of the dwelling, like in a car:

1. switching the space conditioning off or to economy mode to reduce energy consumption;
2. closing all blinds for security;
3. switching off all the lights.

The second scenario is the central opening, which re-starts all functions disabled from the previous scenario.

Table 5 - Bill of material for solution # 1 (Class A)

Quantity	Description	Cost (€)
1	Power supplier 320 mA	249,80
3	Actuator 4 channels KNX-Easy	169,00
5	Actuator 1 channel KNX-Easy	236,70
8	Contact interface 4 channels KNX-Easy	282,20
2	Infrared motion sensor KNX-Easy	105,00
1	Box 8P. (4+4)	1,40
5	Motor control 1 channel KNX-Easy	298,70
2	Twilight sensor 1-100lux IP55	56,20
7	Security magnetic sensor RF	79,20
1	Master control panel KNX-Easy	331,20
4	Thermostat KNX-Easy	250,40
	Total equipment cost	2094,00

Note: costs of all components have been taken from the best economic offer collected by the customer. Labour is estimated at 1370,00 €.

In the table above all the main components of the automation system needed for Solution #1 have been listed.

Costs

The total cost of material and labour power is equal to 3.433,37 € excluding VAT.

Solution #2 (Class B)

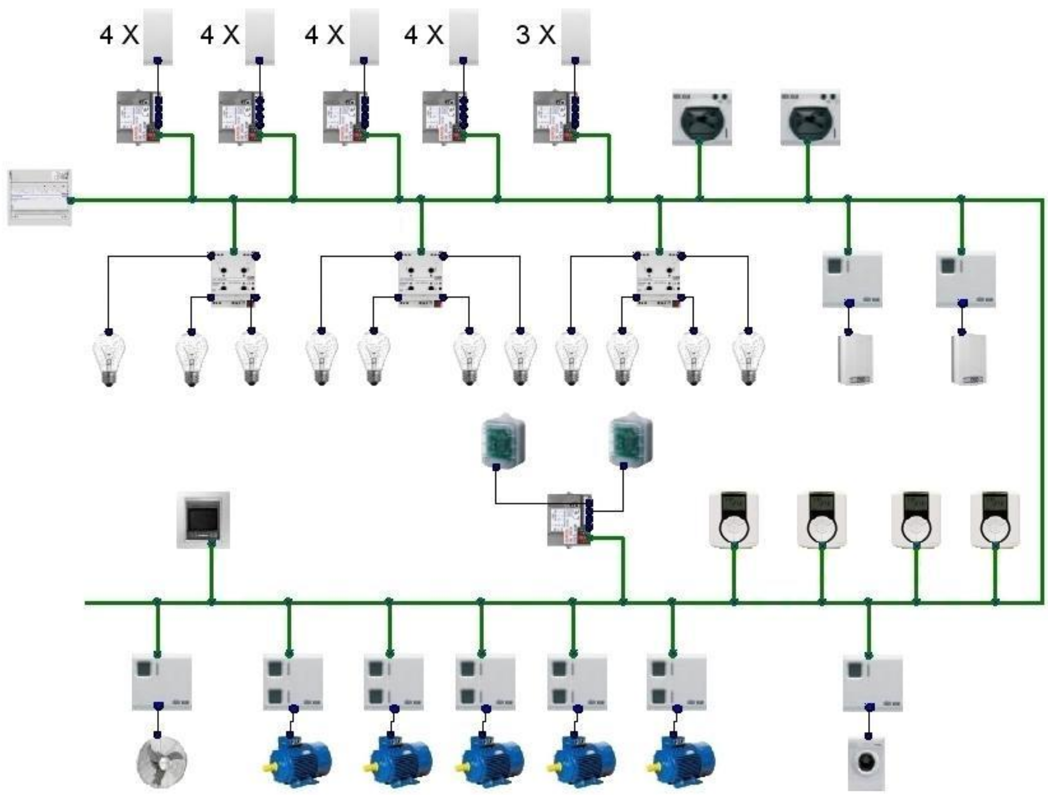

Figure 5 - Suggestive scheme of the BUS of solution #2

The second proposed solution provides for the same lighting and ventilation components as the first solution. The HVAC system is not interfaced with the windows, so it is not possible to turn off the local heating/cooling terminal with an opened window. The blind motion control is automatic through twilight sensors (as for solution # 1). The control panel allows the automatic supervision of whole system, allowing also control of climate parameters and their scheduling per area. With solution #2, the control panel also controls the actuator connected to electrical appliances, allowing a better use of the twin rate tariff. In the following table all the main components of the automation system needed for Solution #2 have been listed. To be noted that there are not seven magnetic contacts and the interfaces became six instead eight.

Table 6 - Bill of material for solution #2 (Class B)

Quantity	Description	Cost (€)
1	Power supplier 320 mA	251,50
3	Actuator 4 channels KNX-Easy	170,10
5	Actuator 1 channel KNX-Easy	238,30
6	Contact interface 4 channels KNX-Easy	213,10
2	Infrared motion sensor KNX-Easy	105,70
1	Box 8P. (4+4)	1,40
5	Motor control 1 channel KNX-Easy	300,70
2	Twilight sensor 1-100lux IP55	56,60
1	Master control panel KNX-Easy	333,40
4	Thermostat KNX-Easy	252,10
	Total equipment cost	1958,00

Note: costs of all components have been taken from the best economic offer collected by the customer. Manpower have been estimated to be 1282,00 €.

Costs

The difference in cost of the system in question compared to a traditional amounts to € 3,205.02 excluding VAT, about 7% less than solution #1.

Solution #3 (Class C)

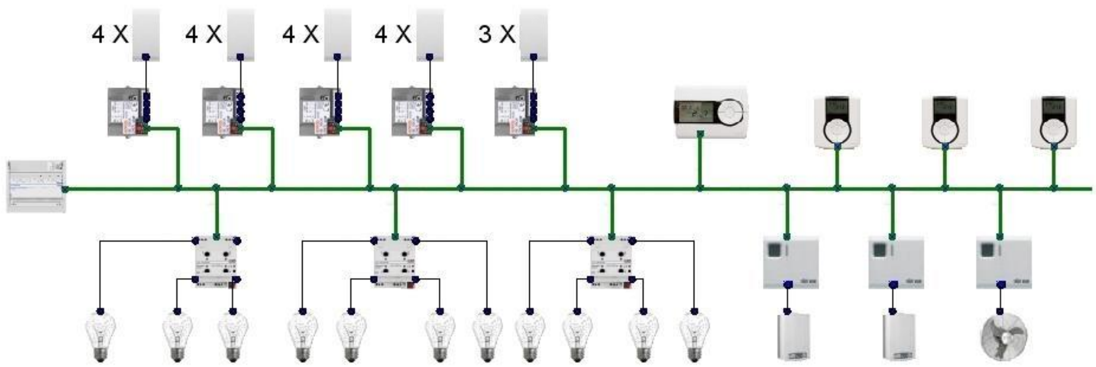

Figure 6 - Suggestive scheme of the BUS of solution #3

Compared to the previous cases the third solution involves a substantial decrease in automation. The designer has kept blind motion, but only manually and not automatically through the light sensor. Sensors, actuators and motor control are therefore not listed in the bill of material of this solution.

The lights are always controlled via the system bus and actuators, but there are no presence sensors at the entrance and in the hallway. One night scenario allows turning off all the lights to avoid unwanted consumptions, due to any neglect of the couple.

A thermostat connected to the system bus schedules and controls the air conditioning in the areas of the flat according to the needs of the inhabitants.

Over the time periods when the house is uninhabited, it is possible to implement the climate scenarios, turning off air conditioning or regulating the temperature of various areas (according to the needs of the couple),.

In the following table main components required for solution 3 are listed. This solution provides a basic level of automation, but, at the same time the possibility to easily expand the number of home automation components, improving the level of automation, comfort and energy savings.

Table 7 - Bill of material solution #3 (Class C)

Quantity	Description	Cost (€)
1	Power supplier 160 mA	174,60
3	Actuator 4 channels KNX-Easy	179,40
3	Actuator 1 channel KNX-Easy	150,80
5	Contact interface 4 channels KNX-Easy	187,20
3	Thermostat KNX-Easy	199,30
1	Cronothermostat KNX-Easy	90,60
	Total equipment cost	1008,00

Note: costs of all the components have been taken from the best economic offer collected by the customer. Manpower have been estimated to be 655,00 €.

Costs

In the solution #3 the quantity of used components is quite small, keeping a lower total cost. The designer estimated the delta cost of this solution equal to 1.636,50 € plus VAT.

ECONOMICAL EVALUATION

Expected savings

Due to lack of detailed information on load profiles (as usual in domestic environments), expected savings coming from the implementation of design solutions outlined in the previous paragraphs have been estimated on the basis of EN15232 BAC factors. The BAC factors method is based on statistical factors provided by standard and based on the:

1. User profile
2. Internal heat gains
3. Control accurancy and quality

This led to the calculation of the figures shown in the following table.

Table 8 - Energy savings estimation by equipment and system for different building automation classes according to EN 15232.

System class	C	B	A
Lighting system	24,33 kWh	45,67 kWh	48,67 kWh
Water Heating	--	--	--
Heating system	981,00 kWh	2155,00 kWh	2845,00 kWh
Cooling system	48,67 kWh	91,33 kWh	97,33 kWh
Appliances and other	--	--	--
Total	1054 kWh	2292 kWh	2991 kWh

The energy consumption in the 3 years before the renovation was used as the baseline for estimating energy savings. savings was the .For each design solution consumption were calculated by multiplying the coefficient kn for heat and electricity consumed by the couple in one year. The total energy savings ranging from 9.0% of the solution # 3, to 25.4% of the solution #1.

Table 9 - Energy consumption of different design solutions (Automation classes defined by EN15232)

Design solution	Gas consumption (kWh/year)	Electrical consumption (kWh/year)	Total consumption (kWh/year)	Energy savings (kWh/year)	CO_2 emission reduction (kg/year)
Before the renovation (Class D)	10.776	984	11.760	-	-
# 3 (Class C)	9.795	911	10.706	1.054 (9,0%)	238,9
# 2 (Class B)	8.621	847	9.468	2.292 (19,5%)	515,8
# 1 (Class A)	7.931	838	8.769	2.991 (25,4%)	666,9

Energy costs after the renovation

The annual cost of energy consumption excluding VAT and the relative savings obtained comparing the existing system with the automated system are summarized in Table 11 and in Table 12.

Table 10 - Energy annual costs estimated on the basis of the energy bills of the previous 36 months

Energy source	Cost (€/kWh)
Natural gas	0,0613
Electricity (Band A[1])	0,1584
Electricity (Band B[2])	0,3078

Energy savings and costs have been calculated referring to the values shown in Table 10.
As shown by Table 11, the thermal energy costs represent an important percentage of the total energy cost and subsequently thermal energy cost savings are the highest (Table 12). Simple payback is also shown in Table 12 even if it’s never a good index to evaluate EE investement because payback does not show savings after the payback time even if such savings are the real value of the EE investement.

1 Band A: consumption in the range from 19:00 to 8:00 from Monday to Friday, Saturday, Sunday and national holidays.
2 Band B: consumption in the range from 8:00 to 19:00 from Monday to Friday.

Table 11 - Energy costs

Design solution	Thermal energy cost (€/year)	Electrical energy cost (€/year)	Total energy cost (€/year)
Before the renovation (Class D)	660,55	203,85	864,40
# 3 (Class C)	600,44	188,76	789,20
# 2 (Class B)	528,44	175,51	703,95
# 1 (Class A)	486,16	173,68	659,84

Table 12 - Saving related to each design solution

Design solution	Thermal energy savings (€/year)	Electrical energy savings (€/year)	Consuption shift savings (€/year)*	Total savings (€/year)	Simple payback (years)
Before the renovation (Class D)	-	-	-	-	
# 3 (Class C)	60,11	15,08	0,00	75,19	1637/75 = 21.8
# 2 (Class B)	132,11	28,33	67,19	227,63	3205/228 = 14,1
# 1 (Class A)	174,38	30,17	67,19	271,74	3433/272 = 12,6

* Note: savings corresponding to the shift a greater share of consumption to band A was estimated assuming that approximately 450 kWh, representing 13% of total electricity consumption, mainly related to the use of large white goods can be moved nighttime (A). From here, 450 kWh * (0.3078 to 0.1584) = 67.19 €

CONCLUSION

The owners compared the initial higher cost of equipment due to the inclusion of home automation devices and systems together with the payback time, for the three different solutions, and selected solution # 1. This solution has the lower payback time, results in the greatest reduction in energy consumption and allows considerable comfort. In the future, features and devices can be seamlessly integration with the control system, , keeping in line with technological innovations.

The savings could have been achieved also at no cost by the owners, by simply remembering to swich on and off appropriately the appliances but the statistics and experience show that in practice, an automated system works better than a human for energy savings, for the following main reasons:

1. Humans don't pay enough attention to energy savings because they are focused on they other main activities.

2. The human senses are usually not sensitive enough to recognize in real time the need or the possibility of switching off a service. For example, lighting is switched on in the morning before sunrise. During the day the contribution of daylight is more than sufficient, but our senses do not immediately perceive that the light level is more than the minimum needed but are only aware of this when the level becomes really excessive.

One year later the analysis of energy bills showed actual savings of 292 € in comparison with the pre renovation energy bills of 864 € (and the savings were higher than the predicted 272 €). One year is not a sufficiently meaningful statistical period time, but the owerns were satisfied with their investment.

Table 13 - Solution # 1 Cash flow

Year	Solution #1 cash flow (€)	Earns

		(€)
0	-3.776,71	-3.776,71
1	399,71	-3.377,00
2	391,87	-2.985,13
3	384,19	-2.600,94
4	376,65	-2.224,29
5	369,27	-1.855,02
6	362,03	-1.492,99
7	354,93	-1.138,06
8	347,97	-790,09
9	341,15	-448,94
10	334,15	-114,49
11	**218,55**	**104,07**
12	214,27	318,33
13	210,06	528,40
14	205,95	734,34
15	201,91	936,25
16	197,95	1.134,20
17	194,07	1.328,27
18	190,26	1.518,53
19	186,53	1.705,06
20	**182,87**	**1.887,93**

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Economic and Environmental Analysis of Residential Heating and Cooling Systems: A Study of Heat Pump Performance in U.S. Cities

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Abstract

As more efficient heat pump systems have been introduced in the residential HVAC market over the past few years, including systems that rely on inverter (INV) technologies or variable speed motors, policymakers and energy efficiency program administrators have started to pay close attention to these technologies as key efficiency measures to reduce energy consumption, CO_2 and air pollution.

In a recent study, Synapse Energy Economics (Synapse) examined the hypothetical operation of two "efficient" HVAC technology options—a 2-stage heat pump and an inverter heat pump—for single family homes that were built around 1990 and that require replacement of a ducted HVAC system. Synapse then compared those options to a reference-case option—consisting of an efficient natural gas furnace and a central air conditioning system—on the basis of energy, environmental, and economic impacts for 11 U.S. cities with varied climates.

This was one of the first studies, if not *the first*, to use detailed performance curves of a ducted inverter heat pump system in the U.S., and to analyze and compare the energy and environmental impacts of these HVAC options on an hourly or seasonal basis.

This paper discusses the methodologies and results of our analysis. Key findings include the following:

- **Which options are most cost-effective?** In all cities studied, the INV heat pump SEER 16 option had the shortest payback, the highest benefit cost-ratio, and offered the largest net benefits to consumers.
- **Which provided the greatest CO_2 reductions?** The INV heat pump saw significantly more CO_2 savings across all studied cities (except Chicago and Minneapolis) than the 2-stage heat pump option.
- **In which cities are consumers, the society, or both likely to gain the most benefit from installing one of the studied HVAC technologies?** Among all cities studied, we found that Atlanta and Houston provided the best balance among all analysis results, including customer payback, benefit cost ratio, and net benefits and CO_2 reduction.

The Case Studies

Three single-family-home replacement HVAC technology options (or combinations of options) were selected for this analysis, which are summarized in Table 1. Option 1, which consists of a central air conditioning unit (CAC) plus a natural gas (NG) furnace, is a reference case against which the energy, environmental, and economic impacts of the other options are compared. These technology options are intended to represent the choices that owners of single-family homes with a ducted HVAC system are likely to face when they plan to replace their heating and cooling systems. All of the heat pumps shown are 4-ton units (or 48,000 Btu).

[1] Mike Duclos, a HERS Rater and a Certified Passive House Consultant, analyzed annual heating and cooling energy loads using the REM/Rate™ model as a subcontractor to Synapse for the original analysis upon with this paper was based.

Table 1: Studied HVAC Systems[2]

	Option 1: CAC & NG Furnace	Option 2: 2-stage HP (SEER 16)	Option 3: INV HP (SEER 16)
Cooling	SEER 13 CAC	SEER 16 2-stage heat pump (ducted)	SEER 16 inverter heat pump (ducted)
Heating	95% AFUE NG furnace	HSPF 9.5 2-stage heat pump; 95% AFUE NG furnace backup at 15°F	HSPF 9.5 inverter heat pump; 95% AFUE NG furnace backup at 5°F

As noted in Table 1, our study assumed a 2-stage heat pump switches its operation to a back-up gas furnace at 15°F, and an inverter heat pump switches its operation to a back-up furnace at 5°F.[3]

The 11 cities addressed in this analysis include Atlanta, Boston, Chicago, Houston, Los Angeles, Miami, Minneapolis, New York City, Phoenix, Portland, and Salt Lake City. These cities were selected to cover broad climate regions, and to include cities and states that have aggressive state and utility energy efficiency programs.

Figure 1 shows a map of the selected cities and their respective climate zones based on heating degree days (HDD) and cooling degree days (CDD).

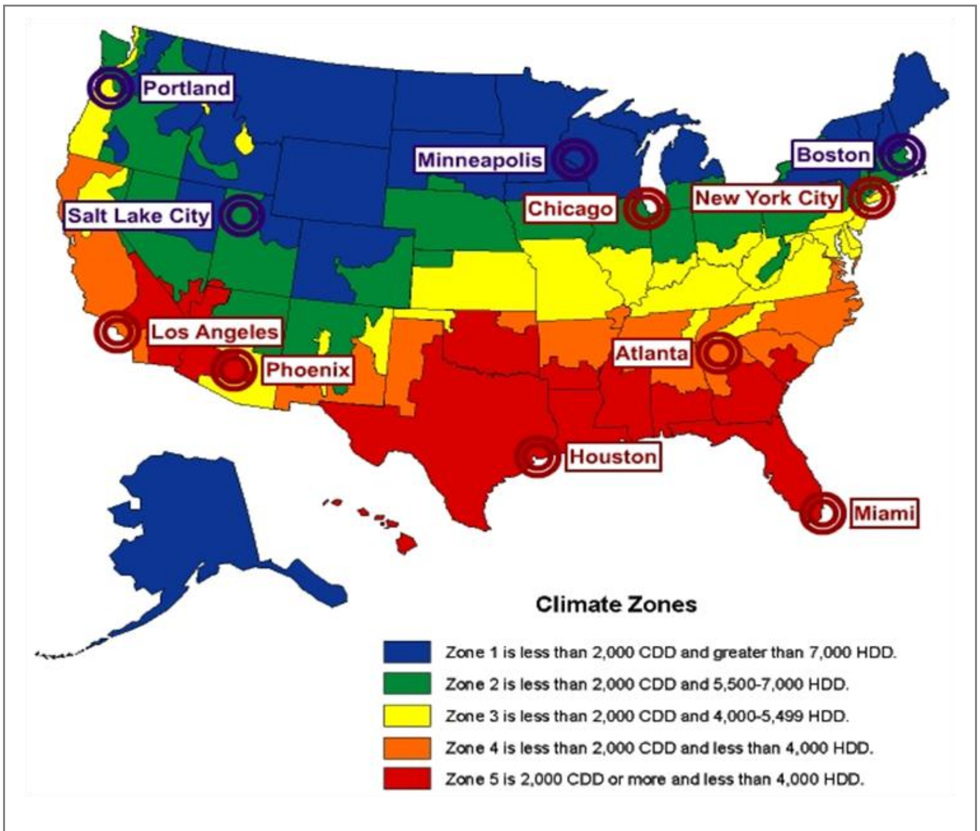

Figure 1: The selected cities superimposed on a climate map of the U.S. [1]

[2] SEER and HSPF stand for Seasonal Energy Efficiency Ratio and Heating Seasonal Performance Factor, respectively. SEER is a standard efficiency metric used in the U.S. for the cooling performance of air conditioners. HSPF is a standard efficiency metric used in the U.S. for the heating performance of heat pumps. Both SEER and HSPF are calculated as Btu energy output over Wh electrical input during one season at certain test conditions. AFUE represents efficiency of furnaces and boilers and stands for Annual Fuel Utilization Efficiency.

[3] These temperature thresholds were set to minimize the source energy consumption in the two coldest cities for this study, Boston and Minneapolis.

Methodology and Assumptions

HVAC Performance Data

HVAC performance data for CAC and the 2-stage heat pump were obtained from publicly available data sources. We reviewed manufacture specifications from Goodman, Carrier, and Acadia as well as the DOE building energy simulation software's underlying data, and decided to use Goodman's manufacturer data sets for central AC and the 2-stage heat pump because (a) they are comprehensive and reflected changes in performance given changes in indoor humidity and ambient temperature; and (b) the company has significant market share in heat pump technologies. Detailed performance data for the inverter heat pump were obtained from a global HVAC manufacture company which is developing inverter heat pumps for the U.S. market. Comparisons of heating and cooling performance for these HVAC options are presented in Figure 2 and Figure 3. Figure 2 shows that INV heat pump systems perform significantly better on average than the reference CAC and 2 stage heat pump systems for cooling when they are operating at partial load conditions and at non-extreme temperatures, as indicated by "INV Low" lines.

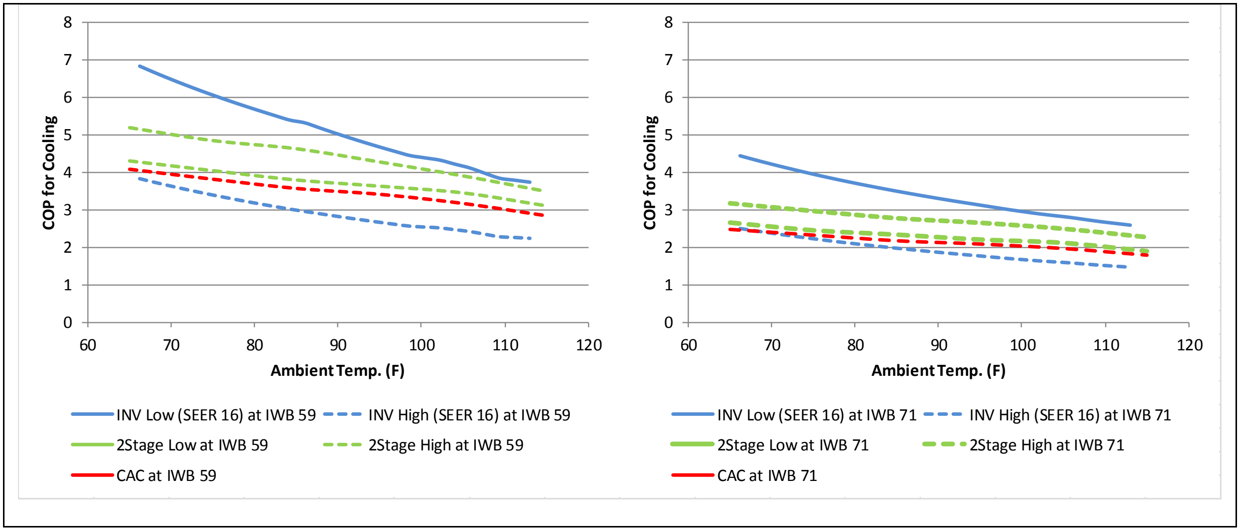

Figure 2: Cooling performance comparison between INV HP SEER 16, 2-stage HP (at Indoor Wet Bulb or IWB 59 on left, at IWB 71 on right), and CAC (at IWB 59 on left, at IWB 71 on right).[4,5] [2],[3],[4]

[4] While Figure 2 uses indoor wet bulb (IWB) 59 and 71, data for other IWB points were also obtained and used.

[5] Sensible cooling outputs were used to estimate COP values. Sensible output over total output ratios for the 2-stage HP were used to estimate COP and consumption for the INV HP because sensible output data for the INV HP were not available.

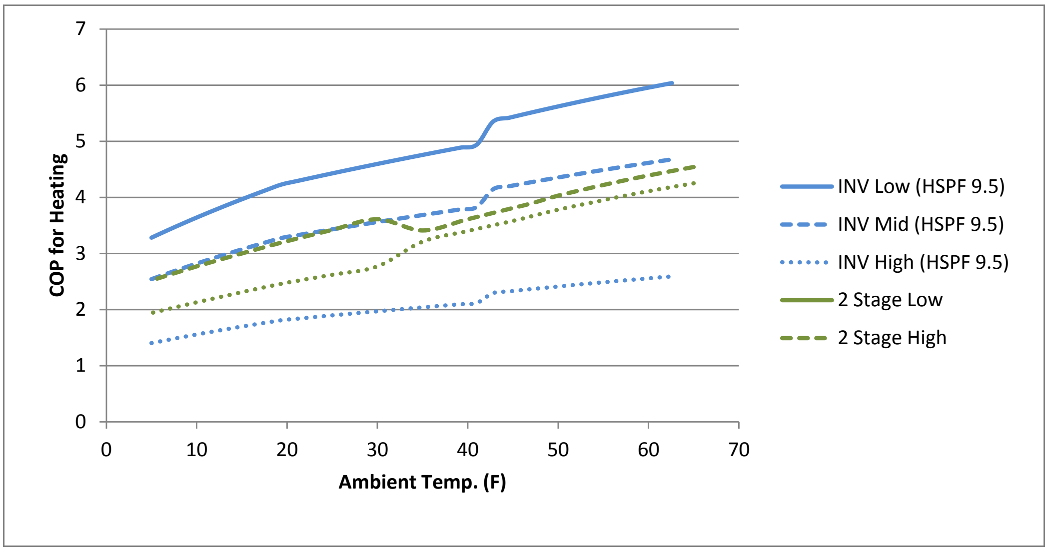

Figure 3: Heating performance comparison between HSPF 9.5 INV HP and HSPF 9.5 2-stage HP [3],[4]

Synapse's Building HVAC Energy Analysis Model

Synapse developed its own integrated, spreadsheet-based model (the Synapse Building HVAC Energy Analysis Model) to estimate energy consumption and energy savings, and to analyze the associated economic and environmental impacts for single family houses in the 11 U.S. cities. This model provides a rigorous first-cut analysis of efficient heat pumps and natural gas furnaces, built upon detailed analysis of climate data, building characteristics, HVAC performance curves, avoided energy costs, retail energy prices, and avoided emission factors for each study region. The model is composed of two major components: (a) the HVAC Energy Consumption Model, and (b) the HVAC Economic and Environmental Analysis Model.

HVAC Energy Consumption Model

This model was used to estimate hourly consumption for each technology option in each city based on hourly average heating and cooling sensible load factors (kBtu/F per house), hourly climate data (e.g., temperature and humidity), HVAC performance, and heating back-up temperature setting. A detailed model house was developed for each city to specify building structure, insulation levels for various parts of the house, appliances, and equipment based on publicly available data sources and the authors' experience with building energy codes and practices. Synapse incorporated the model house for each city in REM/Rate™, a widely used building energy model for code compliance, and estimated annual load by city in order to produce annual total energy consumption.[6][5] Annual total consumption was then divided by total hourly heating and cooling degree hours to estimate hourly "average" sensible load factors (kBtu/°F/hr). Hourly climate data were obtained from the Typical Meteorological Year 2 (TMY2) data set, available from the National Solar Radiation database.[6] The load factors were then applied to temperature in each hour to estimate hourly load. HVAC curves which account for latent load were then used to estimate hourly consumption based on hourly load.

HVAC Economic and Environmental Analysis Model

This model was used to estimate the economic and environmental impacts for each "efficient" HVAC option in terms of total energy costs, HVAC costs, and CO_2, NOx, and SO_2 emissions caused by an on-site reduction or increase in energy consumption (as compared to the reference case).

For the economics of efficient HVAC systems, we analyzed simple payback years, benefit cost ratios, and net benefits from both the consumer and societal or regional perspectives. The Total Resource Cost (TRC) test, which is the tool most widely used to evaluate the economics of utility programs in

[6] The consumption outputs from REM/Rate™ do not include consumption associated with latent cooling load.

the U.S., was used to evaluate the total lifecycle benefits and costs of efficient HVAC systems from a regional or societal perspective, which includes the impacts on all utility customers. The TRC benefits and costs in our analysis are represented as avoided electricity and natural gas cost impacts, plus the difference in the installed costs between efficient measures and the reference measures. The Participant Cost (PC) test was used to evaluate the economics of energy efficiency from the perspective of consumers who install efficient systems. The PC benefits and costs are represented as energy bill impacts based on "retail rates," plus the difference in the installed costs between the efficient options and the reference option, minus any program incentives.

Some key assumptions and methods are presented as follows:

- Our economic and environmental analyses reflect the cost and benefit of operating HVAC equipment for its entire life, which we assume to be 18 years. A real discount rate of 6 percent was used to estimate the present value of benefits and costs.
- Consumer benefits were estimated based on historical regional retail electricity and natural gas rates based on the Edison Electric Institute (EEI) Typical Bills report and the regional electric cost forecasts available in the Energy Information Administration (EIA)'s Annual Energy Outlook (AEO) 2010. Further seasonal natural gas retail prices were developed using historical price data.[7]
- Societal or regional benefits were estimated based on our estimates of avoided energy costs for electricity and natural gas. Avoided costs represent the costs *all* energy customers (including those who invested in energy efficiency and those who did not) could avoid. However, as a conservative measure, our analysis did not include avoided transmission and distribution capacity costs and various other benefits. [7]
- Avoided natural gas cost is best represented by the wholesale natural gas price plus a certain portion of the retail margin price, both of which vary by season.[8] The retail margin is the difference between residential prices and wholesale prices; we assumed 35 percent of retail margin can be avoided.[9] [9] Finally, we applied seasonal price variation factors based on NYMEX natural gas future monthly prices and estimated levelized seasonal costs for each city.[10]
- Our avoided electricity cost consisted of avoided electricity costs and avoided power plant capacity costs. Seasonal and peak and off-peak avoided electricity costs were estimated based primarily on (a) the wholesale electricity prices in 2010, (b) regional electricity price projections, and (c) seasonal and time-of-use price factors, available from the AEO 2010 [11], the Federal Energy Regulatory Commission's website [12] and the Independent System Operators (ISOs).
- Our avoided capacity cost was $100/kW-year, which roughly represents the cost of a natural gas peaking unit.[13]
- The costs of the HVAC systems except the INV heat pump are based on data from a U.S.-wide commercial HVAC distributor.[14] The costs we decided to use for the natural gas furnace, the central AC, and the 2-stage heat pump are $1374, $2005, and $3858, respectively. Based on our discussion with the HVAC company that provided the INV performance data, we decided it is reasonable to assume the cost of the INV heat pump is equal to the cost of a 2-stage heat pump at the same SEER and HSPF level.

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[7] A more comprehensive TRC test should include other benefits such as avoided transmission and distribution costs, avoided cost of environmental compliance and avoided emissions, and quantifiable non-energy benefits (e.g., water savings, increased property values, improved safety and comfort).[8]

[8] The AEO 2010 regional natural gas prices for the electric power sector was used as a proxy for city gate wholesale natural gas prices.

[9] A study called Avoided Energy Supply Costs in New England determined 70% of the retail margin is avoidable. However, how much can be avoided depends on region and whether and how fast the industry is growing and increasing natural gas sales. Considering this fact, we adopted a more conservative approach and used 35% as an avoidable retail margin factor across the study cities.

Average retail prices and avoided costs for electricity and natural gas are presented in Table 2.

Table 2: Summary of Average Retail Price and Costs for Electricity and Natural Gas

	Elec. Price (cents/kWh)	Average Avoided Elec. Cost (cents/kWh)[10]	Average NG Price ($/mmBtu)	Average Avoided NG Cost ($/mmBtu)
Atlanta	8.7	3.9	14.1	10.7
Boston	15.3	5.0	15.1	10.4
Chicago	10.5	3.6	10.7	7.8
Houston	7.6	3.9	11.1	8.2
Los Angeles	15.3	4.1	11.5	8.6
Miami	9.7	4.9	14.1	10.7
Minneapolis	9.1	2.8	10.8	8.2
New York City	21.2	5.5	13.1	9.4
Phoenix	10.5	3.5	10.8	8.5
Portland	10	3.8	11.5	8.6
Salt Lake City	8.1	3.8	10.8	8.5

Avoided emission rates for NO_x, SO_2, and CO_2—which were used to estimate emissions avoided due to a reduction in energy consumption with efficient HVAC options—are based on our analysis of historical hourly emissions data. In this analysis, we determined the mix of marginal generation units during each hour for each U.S. EPA eGrid region.[15][11] The weighted average emissions rate from this marginal mix is an estimate of the displaced emissions rate. In this analysis, the marginal (or avoidable) emissions rate was estimated empirically by quantifying which units had a marginal behavior—i.e., ramp with changes in demand on a regular basis. The method used the Continuous Emissions Monitoring (CEMS) data of the US EPA's Clean Air Market Division (CAMD).[16] This CAMD dataset contains hourly reported generation, CO_2, SO_2, and NO_x emissions for fossil boilers over 50 MW in size.

Energy Savings and Consumption Analysis Results

Cooling Energy Savings

Figure 4 below shows annual cooling energy savings results 1) in MMBtu (on the left side), and 2) as a percent of the reference case's total energy consumption (i.e., CAC + NGFurnace) on the right side. Overall, the cities with hot climates, such as Houston, Miami, and Phoenix, had three to four times more annual savings than the other cities in absolute terms (MMBtu). Average temperature, maximum temperature, cooling degree days (CDD), and degree days above 87°F for these cities (along with the other cities) are presented in Table 3. Key findings for each of the efficient HVAC options are summarized below:

- **2-stage Heat Pump:** The annual cooling energy savings for the 2-stage HP relative to the reference case consumption was about 20% for each city, and ranged from 0.5 MMBtu per year in Portland to about 3.6 MMBtu per year in both Phoenix and Miami.
- **INV HP SEER 16:** The cooling energy savings for the INV HP SEER 16 was more than 30% for the majority of the cities, except Los Angeles, Phoenix, and Salt Lake City. The absolute

[10] The values do not include the avoided capacity cost of $100/kW-year. For example, the annual avoided capacity value for the INV HP SEER 16 is $52 in New York City given that our model estimates that the system provides 0.56 kW peak savings.

[11] Marginal units respond to fluctuations in demand and price. As the demand for electricity grows during a typical day, more expensive units are added as required; consequently, if less energy is demanded, these expensive units will drop off sequentially and are hence "avoided."

savings ranged from 0.7 MMBtu in Portland to 7 MMBtu in Miami. Houston had the second highest cooling savings at 4.8 MMBtu.

In general, for all the heat pump technologies, cities with humid, hot climates saw the most cooling savings compared to the reference case, and cities with dry, hot climates saw the least cooling savings compared to the reference case. Cities with cooler climates tended to see intermediate savings compared to the reference case. In Phoenix, a city with an extremely hot climate, the inverter heat pump did not perform as well as it did in other cities (relative to the reference case), while the 2-stage heat pump maintained a lower, but more standard percent savings across all cities, as shown in Figure 4. This is mainly because the INV HP performance has a more significant decrease than the performance of the 2-stage HP in Phoenix's extremely hot climate. (See Figure 2 for the HVAC performance, and Table 3 for the climate data for the study cities.)

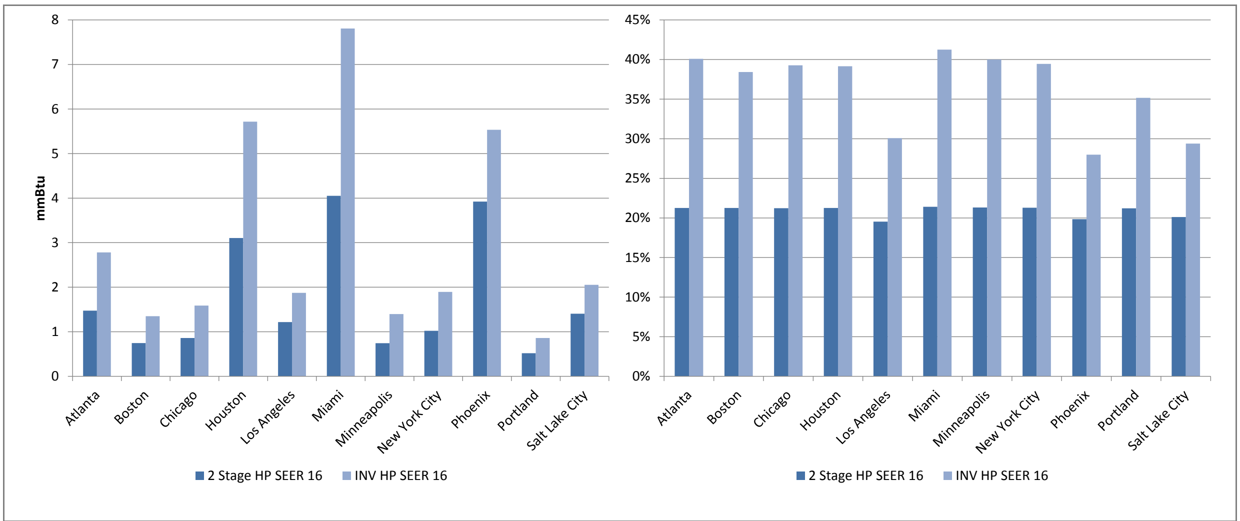

Figure 4: Annual Cooling Site Energy Savings in MMBtu (left) and as a Percent of the Reference Case Energy Consumption (right)[12]

Table 3: Climate Statistics by City [6][13]

	Annual Average Temp (F)	Max	Min	HDD at 65°F	Degree Days under 32°F	CDD at 70°F	Degree Days above 86°F	Average Rel. Humidity (%)
Atlanta	61	97	12	3,265	18	904	8	65
Boston	51	92	5	5,959	56	346	2	59
Chicago	50	96	-9	6,586	78	520	5	58
Houston	68	97	14	1,771	5	1,798	29	72
Los Angeles	63	98	35	1,707	0	427	3	53
Miami	76	93	38	218	0	2,557	19	72
Minneapolis	45	95	-21	8,049	109	422	3	60
New York City	54	95	4	5,159	45	563	4	59
Phoenix	73	115	27	1,535	0	3,216	90	27
Portland	53	92	20	4,813	8	241	2	43
Salt Lake City	52	101	0	5,919	61	825	19	27

[12] Consumption is presented as consumption to serve sensible load.

[13] "Average Rel. Humidity (%)" refers to average humidity during cooling degree days for each city, and is different from annual average humidity.

Heating Energy Savings

Figure 5 shows total annual "site" heating energy savings in MMBtu in the left chart, and total annual "source" energy savings as a percent of the reference case consumption in the right chart. The reason to show "source" energy savings instead of "site" energy savings, in relative terms, is to give an alternative comparison between consumption by electricity and consumption by natural gas. Site electricity consumption does not reflect energy lost between electricity generation and delivery to houses.

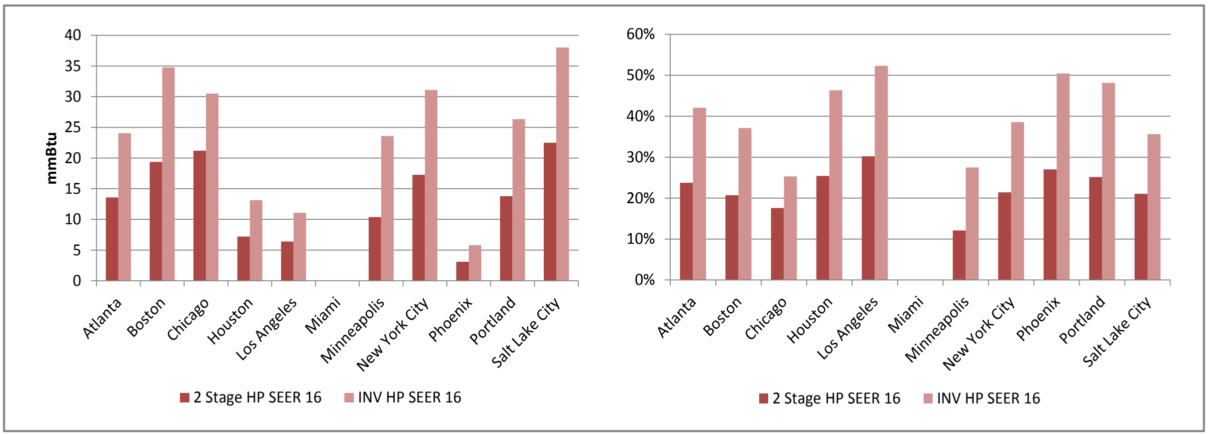

Figure 5: Annual Heating "Site" Energy Savings in MMBtu (left) and Annual Heating "Source" Energy Savings as a Percent of the Reference Case Consumption (right)[14]

The cities with the greatest absolute site heating energy savings were cities with cooler/cold climates such as Boston, Chicago, Minneapolis, New York City, and Salt Lake City. (See Table 3 for the climate statistics for heating). The energy savings for those cities ranged from about 50 to 80 MMBtu, which is roughly five to eight times greater savings than cities with hot climates such as Houston, Los Angeles, and Phoenix. However, the warmer cities had much greater savings when viewed as a percentage of the reference case, as presented in the right-hand chart in **Error! Reference source not found.**. This ability to perform well compared to the reference case is due to the fact that for heating, heat pumps work more efficiently in less extreme weather. Key findings for each of the efficient HVAC options are summarized below:

- **2-stage Heat Pump:** Minneapolis, the coldest city, had the lowest relative source energy savings potential (12%) for the 2-stage HP (excluding Miami, with no heating requirement), while the other cities saved about 20 to 30%.
- **INV HP SEER 16:** All cities (excluding the coldest cities, Minneapolis and Chicago) saved 40 to 50% of the reference case energy consumption.

Economic and Environmental Analysis

Economic Analysis

Figure 6 and Figure 7 present the results of our economic analyses from the consumers' perspective. Based on our review of these results, we found that the INV HP SEER 16 was the most attractive investment for all of the study cities for consumers. This is mainly because (a) the cost of the technology is equal to or smaller than the costs of the 2-stage HP, and (b) the energy savings resulting from this HVAC option are significantly higher than the savings from the 2-stage HP.

Additional economic findings (from the consumer perspective) are summarized below:

- **Simple payback:** The INV HP SEER 16 had the best (i.e., shortest) payback for all cities, averaging approximately 2 to 3 years in all cities except New York. (See Figure 6) New York had a long payback period or did not pay back at all, depending on the HVAC system,

[14] We assume on-site electricity utilizes only 35% of the primary energy input at power generation

because the lifetime costs for these systems exceed the lifetime benefits. The higher lifetime costs in New York were due to the city's highest retail electricity rate among the study cities, along with an average retail natural gas rate.

- **Benefit cost ratio:** The INV HP SEER 16 provided the highest benefit cost ratio for all cities. (See the left chart in Figure 7.) For example, a dollar investment in the INV HP SEER 16 (i.e., the incremental cost of the system over the reference case system) yielded about eight dollars return in Houston, while a dollar investment in the other technology yielded slightly above a dollar return.
- **Net benefits:** In terms of net benefits to consumers, the 16 SEER Inverter HP was the best option for all cities. (See the right-hand chart in Figure 7.) The largest net benefit was slightly over $6,500 with the INV HP SEER 16 in Atlanta.
- **Consumer economics:** The top five cities with good consumer economics with the INV HP SEER 16 were Atlanta, Houston, Portland, Phoenix, and Salt Lake City, due to a combination of favorable retail energy rates for heat pumps, the level of energy savings, and/or low incremental HVAC system costs.

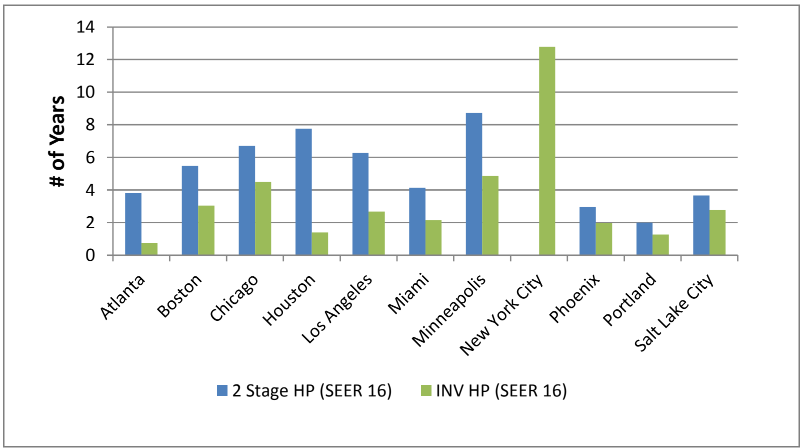

Figure 6: Simple Payback Year Comparison

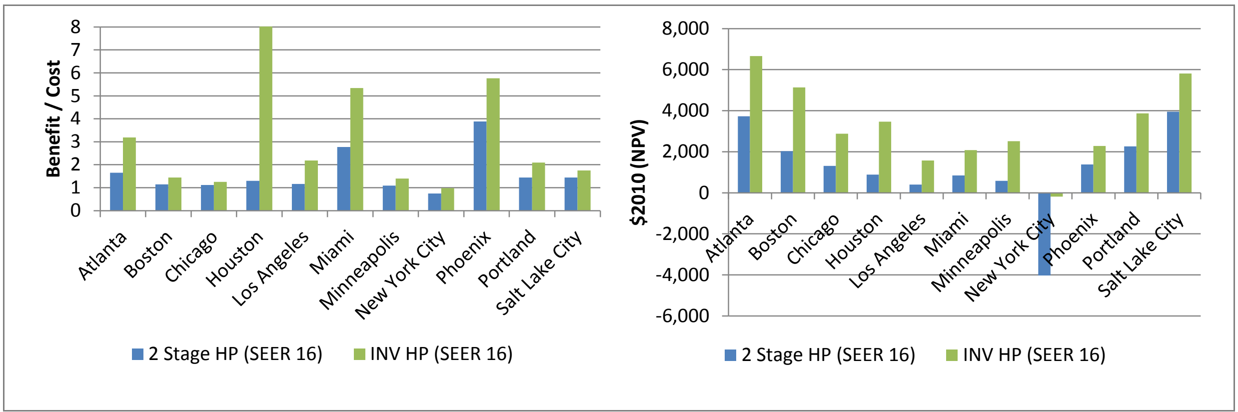

Figure 7: Benefit/Cost Analysis (left) and Net Benefits (right) with the Participant Cost Test

Figure 8 shows the benefit cost ratio and net benefits from the societal/Total Resource Cost (TRC) perspective by HVAC system and city. The TRC perspective differs from the consumer perspective in that the INV HP SEER 16 had the highest benefit cost ratio and highest net benefits among HVAC options for all cities except Portland. This is mainly because (a) the cost of the technology was set equal to the cost of the 2-stage HP, and (b) the energy savings of this HVAC option were significantly higher than savings from the 2-stage HP. Portland is in a winter electricity peaking region, and the use of heat pumps during the winter period for heating requires extra generating capacity. This adds extra costs to the electricity grid instead of providing benefits in terms of reducing peak load.

Among cities, the TRC ratios for the INV HP SEER 16 systems were particularly high in Atlanta, Houston, Miami, and Phoenix, where the INV systems do not require a back-up furnace, and the electricity consumption increase for heating is largely offset by the electricity savings for cooling.

Interestingly, the cities with the highest TRC benefit cost ratios for the INV HP SEER 16 are Houston, Miami, Los Angeles, and Phoenix, which had *lower* net benefits than other cities. Heat pump systems in these cities were relatively small as the mild winter climate in these cities did not require back-up furnaces. Alternately, cities such as Atlanta, Boston, Chicago, and Salt Lake City, which had low benefit cost ratios, provided very high net benefits to consumers across different HVAC types. It appears that these cities had either high energy savings (especially heating savings) or favorable avoided energy costs for heat pumps (i.e., low avoided electricity and high avoided natural gas costs), or both.

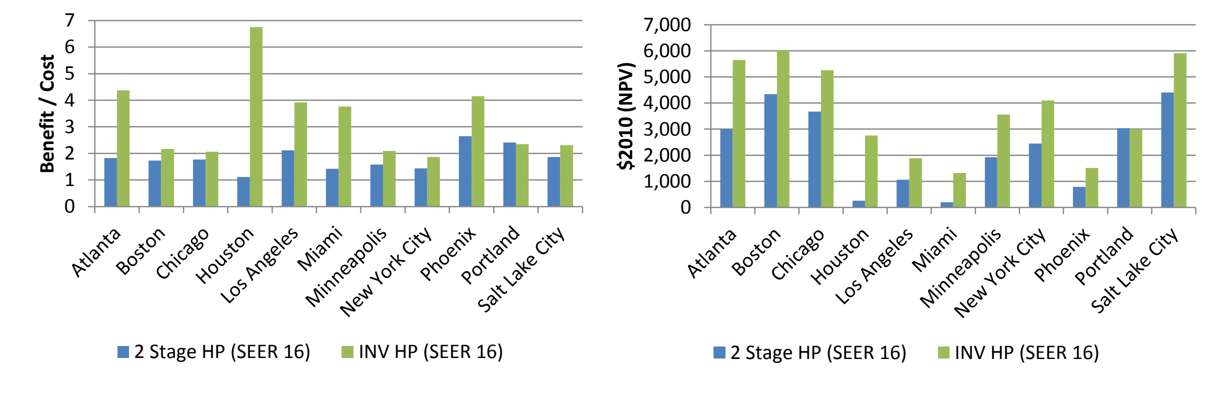

Figure 8: Benefit/Cost Analysis (left) and Net Benefits (right) with the TRC

Environmental Analysis

In terms of lifetime emissions impacts, many cities saw significant CO_2 and NO_x savings with heat pumps, but almost all cities except Miami saw SO_2 emission increases, and Los Angeles and Phoenix saw negligible SO_2 emission increases or decreases. In addition, the cities in the Midwest (Chicago and Minneapolis) saw a significant increase in all emissions (CO_2, NO_x, and SO_2) because this region has significant amounts of coal-fired electric generation on the margin (Figure 9).[15]

Additional environmental findings are summarized below:

- **CO_2 savings:** The INV heat pump saw significantly more CO_2 savings across all cities (except Chicago and Minneapolis) than the 2-stage HP option.
- **NO_x savings:** The INV heat pump option saved NO_x emissions in all cities except Chicago, Minneapolis, and Salt Lake City. The 2-stage HP saved NO_x emissions in all cities except Chicago, Minneapolis, Atlanta, Portland, and Salt Lake City. Among all cities, Boston and New York (which have low emission rates and high energy savings) saved the most emissions.
- **SO_2 savings:** In many of the study cities, SO_2 emissions increased with both HP options because the baseline SO_2 emission rate estimates based on a natural gas furnace are negligible. The increase was again particularly acute in Chicago and Minneapolis. Cities with significant cooling energy savings relative to heating energy savings (i.e., Miami, Los Angeles, and Phoenix) saw some positive SO_2 emission reduction or negligible SO_2 emission increase with INV heat pumps.

[15] This means that marginal emissions from electricity in the region are so high that they exceed emissions from natural gas per mmBtu "heating load."

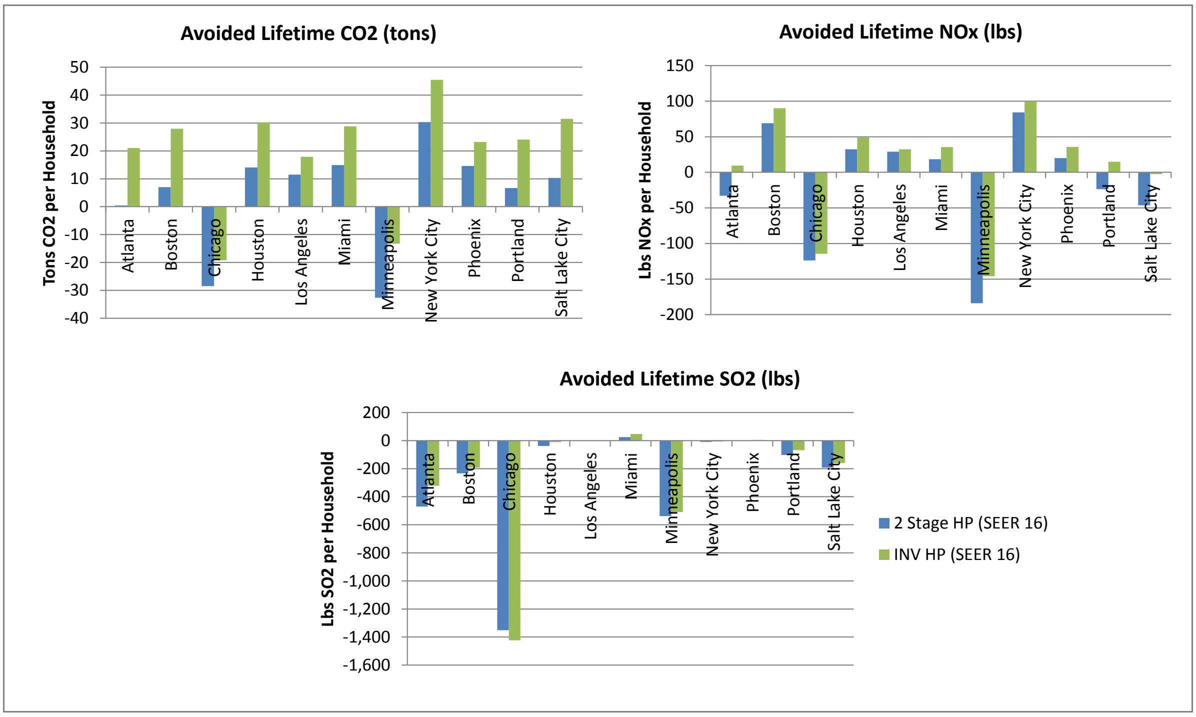

Figure 9: Avoided Lifetime CO2, NOx, and SO2 Emissions (tons or lbs.)

Synthesis of Economic and Environmental Impacts from Consumer and Societal Perspectives

Ultimately, the type of heat pump that makes the most economic and environmental sense for each city depends on the perspective the analysis is being conducted from—particularly whether it is from the consumers' or the societal perspective. Given that our analysis of the different HVAC options found that the INV HP SEER 16 provided the greatest benefits across all cities with a few exceptions, we took a closer look at the energy and environmental impacts of the INV HP by city, and synthesized the results as one total score for each city as shown in Table 4 (below). The higher the score, the better for each analysis category in the table. For example, Atlanta received a score of 11 for payback because it had the shortest payback period among all cities for this technology option, and New York received the lowest score of 1 because the payback for the city was the longest.

Among all cities, we found that Atlanta and Houston provided the best balance among all analysis results, including customer payback, benefit cost ratio, and net benefits with the Participant Cost Test and CO_2 reduction. Salt Lake City, Portland, and Boston rounded out the top five cities.

However, when we consider NOx emission impact, Salt Lake City, the third ranked city, showed reduced benefit from investment in heat pumps (as shown in Figure 9) , In contrast, Houston, the second ranked city, saved a great deal of NO_x emissions with heat pump technologies.

In terms of lifetime SO_2, emissions increased in all cities except Phoenix and Miami with the use of heat pumps, while Los Angles saw negligible emissions increase.

The cities with the lowest total scores were Minneapolis, New York City, and Chicago. The benefit cost ratios and simple payback years were very low for these cities. Additionally, lifetime CO_2 emissions increased for both Chicago and Minneapolis with the use of heat pumps due to the high electricity marginal emission rates in the Midwest region

Also note that New York was the only city that the benefit cost ratios for the 2-stage HP and the INV SEER 16 were below 1 from the consumer perspective, while the ratio for the INV is very close to 1. This means that these technologies do not provide net benefits to consumers in this city. However, lifetime CO_2 and NO_x emission savings in New York were the highest among all cities across all HVAC options, which implies that the net benefits could be significantly increased if monetary values were assigned to such avoided emissions.

Table 4: Economic and Environmental Scores for the INV HP SEER 16 by City

	Payback	PTC Ratio	PTC Net Benefit	TRC Ratio	TRC Net Benefit	CO_2	Total Score
Atlanta	11	8	11	10	9	4	53
Houston	9	11	7	11	4	9	51
Salt Lake City	5	5	10	5	10	10	45
Portland	10	6	8	6	5	6	41
Boston	4	4	9	4	11	7	39
Phoenix	8	10	4	9	2	5	38
Miami	7	9	3	7	1	8	35
Los Angeles	6	7	2	8	3	3	29
Chicago	3	2	6	2	8	1	22
New York City	1	1	1	1	7	11	22
Minneapolis	2	3	5	3	6	2	21

Recommendations

Our analysis shows that when replacing an aging central AC and natural gas furnace system, the INV HP SEER 16 in a single family house with a ducted HVAC system is a very attractive investment from both the consumer and societal perspectives, and also reduces CO_2 emissions. However, more research is needed to verify this finding and detailed results from this analysis. In particular:

a. More heat pump models need to be investigated for their performance, including field data, to ensure that performance data are reasonably accurate.

b. Electricity and fuel price forecasts need to be updated to reflect the most recent forecasts.

c. Avoided emissions analysis could be improved by using updated emissions data and a more sophisticated avoided emission model, such as the U.S. EPA's Avoided Emissions and Generation Tool (AVERT).

d. More precise hourly load factors may provide more accurate results.

e. Adding benefits not included in this analysis will improve the economic analysis of HVAC systems. An expanded analysis could include T&D avoided costs; current and expected environmental compliance costs for NOx, SO_2, and CO_2; and other non-energy benefits.

Nonetheless, the results of our analysis offer valuable information to policymakers, consumers, and HVAC companies by identifying HVAC options that are more economically and environmentally advantageous than a NG heating + central AC combination system, and to what extent.

Based on the results of our analysis, Synapse recommends that policymakers further investigate the benefits of these technologies, particularly the 16 SEER Inverter HP system, and consider them for inclusion in energy efficiency programs at the state and federal levels. State governments and utility or third-party energy efficiency program administrators may want to consider including INV heat pumps as a technology eligible for incentives (e.g., rebates). Additionally, the Federal Government could consider adopting higher federal heat pump standards that reflect the energy efficiency attained by inverter heat pump technologies.

In considering INV heat pumps (particularly the INV HP SEER 16), state agencies and energy efficiency program administrators should consider paying particular attention to Houston, Los Angeles, Phoenix, and regions/states with similar building and climate characteristics due to the societal benefits provided in those cities. Minneapolis and Chicago should be considered last. In light of consumer economics, the regions covering Atlanta, Houston, Salt Lake City, Portland, and Boston are also good places to consider promoting the INV HP SEER 16.

Private companies—such as manufacturers, wholesale HVAC companies, and local HVAC contractors—can utilize the information in this study to effectively market their products and provide useful information to customers who are considering replacing their current HVAC system with one that is more efficient. The information from this study would be particularly useful to customers with homes similar to those analyzed in this analysis: single family homes with a ducted natural gas and central AC system. Private companies may want to begin by promoting these technologies in Atlanta, Houston, Portland, Phoenix, and Salt Lake City, where the consumer economics are strongest.

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High Efficiency Motor and Drive for Residential HVAC

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Abstract

A high efficiency drive for a hermetic compressor application for residential HVAC is presented. The objective of this work is to develop a drive with high power factor and high system efficiency (above 90%) that can start reciprocating compressors with large differential load with state-of-art technology in a small foot print. A position sensor-less software algorithm is uniquely developed for starting the motor with high differential load using low starting current enabling the drive electronics to have smaller foot print. Field oriented control software optimizes running performance for any load. Software and electronics are designed to take advantage of the unique characteristics of the interior permanent magnet motor. Performance adjustments are possible allowing optimization for audible noise or for system efficiency etc. The drive supports communications and inputs from system controllers and potentially smart grid devices in the future. A laboratory proof-of-concept drive intended for 6 KW output was built to investigate the performance of the proposed drive with embedded software in a practical application. The experimental results verify that the proposed drive achieves nearly unity power factor providing a constant voltage for the inverter with high efficiency. In order to achieve near unity power factor and drive efficiency above 95%, the front end power factor corrected converter was designed using interleaved topology with swinging choke design. The drive and compressor system meets or exceeds new US Government regulations for residential HVAC systems to operate at high SEER values in order to conserve energy. The drive with compressor was tested extensively for the measurement of SEER outputs under different cooling and heating requirements of a residence and different weather conditions. The data obtained shows that the system achieves satisfactory results exceeding the SEER values stipulated by US government.

Energy Background

According to the U.S. Energy Information Administration the average residential home in the US uses 5.6 million Btus or 1640KWh for air conditioning purposes annually. This represents 7.5% of the total average household energy use. Total air conditioning consumption in the US is 0.635 Quads (or quadrillion Btus). Residential cooling is a major energy consumer; efficiency improvements in cooling systems have the potential to greatly impact energy use.

In the United States air conditioning system efficiency is rated in the units of SEER or "Seasonal Energy Efficiency Rating". The SEER rating involves testing the system at various operating conditions, that is, different external temperatures. Each test point is weighted and then all are averaged for the final SEER. The term "EER" is used to describe one of the test conditions only. Units for EER and SEER are British thermal units per electrical watt-hour. EER is related to the globally more common, unit less, COP (Coefficient of performance) by the equation: EER = 3.4 x COP. Similarly SEER is related to the seasonal version of COP, SCOP "Seasonal Coefficient of Performance" by the equation SEER = 3.4 x SCOP.

The minimum SEER permitted in the US is 13 (SCOP = 3.8), and if it were to increase to 21 (SCOP=6) energy consumed for residential air conditioning will reduce by up to 38%. A viable, cost effective variable speed compressor is a key component in realizing this energy usage reduction.

SEER and SCOP are clearly improvements to EER and COP as they account for some variation in operating conditions. However, SEER/SCOP represents a set of fixed loading conditions and weighting factors. It would be most instructive to use operating conditions and weighting factors specifically designed to mimic actual conditions where the particular unit was to be installed.

Driven by existing and future requirements for energy saving for domestic HVAC systems stipulated by the government, a high efficiency motor drive for a hermetic compressor application was designed and developed using state of the art technology with active power factor control. This paper presents each functional block of the system and provides a brief description of each block explained.

Power Factor Background

Power conversion equipment that processes AC (alternating current) power to DC (direct current) such as power supplies or variable speed drives have to use rectification to transform power. Most of these applications are non-resistive and always have low power factor (PF). The power factor of an AC electrical power system is defined as the ratio of the real power (expressed in Watts) flowing to the load the apparent power (expressed in Volt-Amps) in the circuit.

Government agencies around the world, driven by the US Environmental Protection Agency (EPA) and its ENERGY STAR program are announcing new performance standards for active mode performance of the power converters.

Low power factor is expensive and inefficient. Many utility companies charge large commercial and industrial customers an additional fee when power factor is less than 0.95. Low power factor also reduces an electrical system's distribution capacity by increasing current flow and causing voltage drops. It requires an increase in the electric utility's transmission and distribution capacity in order to handle the reactive power component caused by capacitive and inductive loads.

An illustration of a non-power factor corrected electronic drive current waveform is shown in Figure 1. The consequence of low PF "Power Factor" is that a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and transmission and distribution equipment. With the advent of switch mode power supplies (non-linear loads) the problem is even more severe as such loads tend to distort the current drawn from the utility and introduce higher harmonic content. Some certifying agencies specifically IEC 61000-3-2 are requiring that the total harmonic distortion THD shall be less than 5% to comply. In order to overcome the undesired effects of passive rectification, active power factor correction has been implemented in this drive design.

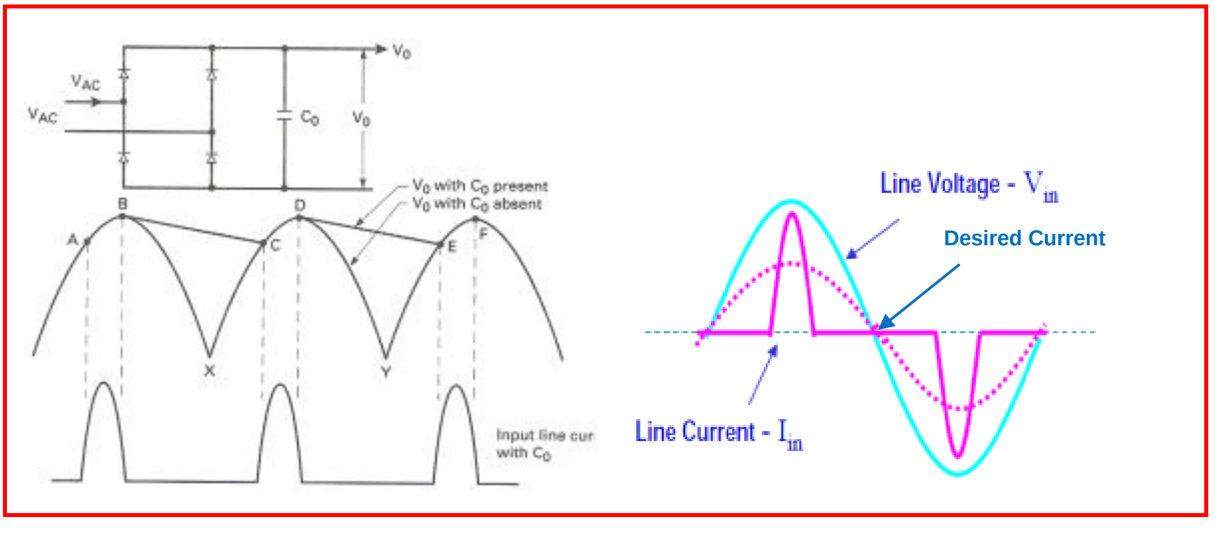

Figure 1: Input current waveform without PFC

Development Goals

Our intent at the beginning of this project was to develop a commercially viable electronic drive for a brushless motor for U.S. residential HVAC systems. These systems typically use large compressors as one compressor cools the entire household. A primary goal was increasing total system efficiency by providing a variable speed motor drive. When used to control the system compressor the drive enables the refrigeration system to operate at its' peak efficiency point under varying temperature conditions. An additional goal was to provide near unity power factor further reducing losses in the electrical power supply.

Design

Overview

A functional block diagram of the drive system is shown in Figure 2. Single phase AC ("AC In") is rectified and unfiltered DC voltage is fed to active power factor controller ("APFC") to provide DC voltage via the DC Link to a three phase inverter. The APFC is designed around a two phase interleaved boost topology for high power factor and efficiency. The microcontroller controls the inverter to drive the motor using a sensor-less Field-Oriented-Control algorithm. Both PFC control and microcontroller provide required safety features to the respective circuits. An overall health monitoring system has been incorporated. Further explanation of the important blocks will be discussed as follows.

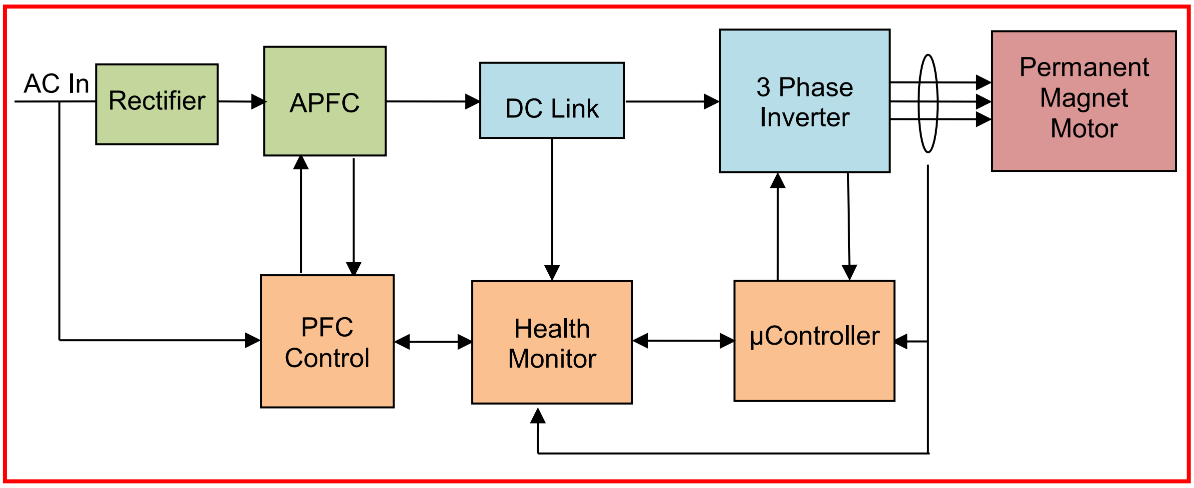

Figure 2: Motor Drive Block diagram

Active Power Factor Controller

Active power factor correction (APFC) can be realized by using standard topologies such as buck, boost and buck-boost depending on the input voltage and DC bus voltage requirement. For this design a boost power factor topology is chosen based on system requirements. The principle of APFC using boost topology is shown in Figure 3. The controller generates PWM "Pulse Width Modulation" signal to turn the switch on and off at a fixed frequency. The pulse width changes depending on the load condition and input voltage level. It gets a reference voltage from the output and current reference from switch current. It also gets a reference input voltage waveform. Based on all the above information the controller makes a mathematical assessment of how much duty cycle is applied to the switch. The switching action of the transistor when on period causes the inductor to store energy and in off period discharges the stored energy in to the bulk capacitor.

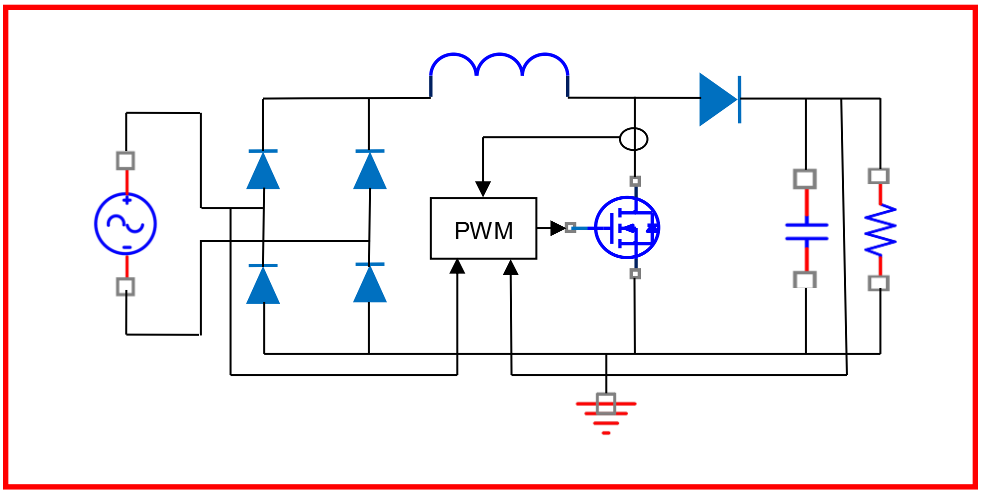

Figure 3: PFC with boost topology

Interleaved 180° Phase Sifted APFC

Given the power requirements for this drive (6 KW), a single stage PF converter will have low efficiency. A two stage converter is proposed with interleaved topology. In the interleaved circuit, the two stages are set 180° out of phase from each other. Therefore the addition of two phases which are 180° out of phase causes the ripple current to cancel when combined additively. The interleaved boost topology for the PFC controller is shown in Figure 4. In figure 4, the output ripple current has decreased significantly. Input current ripple reduction can save significant system cost as the EMI filter and the output capacitors do not need to attenuate large ripple currents.

There are several advantages to the interleaved topology. It allows distributed components which are more efficient as they are smaller for high power applications. Since the components are distributed spatially, thermal management for heat transfer becomes easier and efficient. The circuit can be designed and packaged for an optimum size and efficiency and can be modularized to achieve high power requirements by paralleling several modules.

By phase shifting the control signal by 180°, the input ripple current is reduced significantly allowing smaller filter components for the EMI filter. As a result of input ripple current reduction, core losses in the boost inductor are reduced and allow smaller cores for the inductor.

This phase shifting method of control to operate the switching devices results in reducing the output current ripple by half and increases the switching frequency as seen by the output bulk capacitors. A typical waveform is shown in Figure 4.

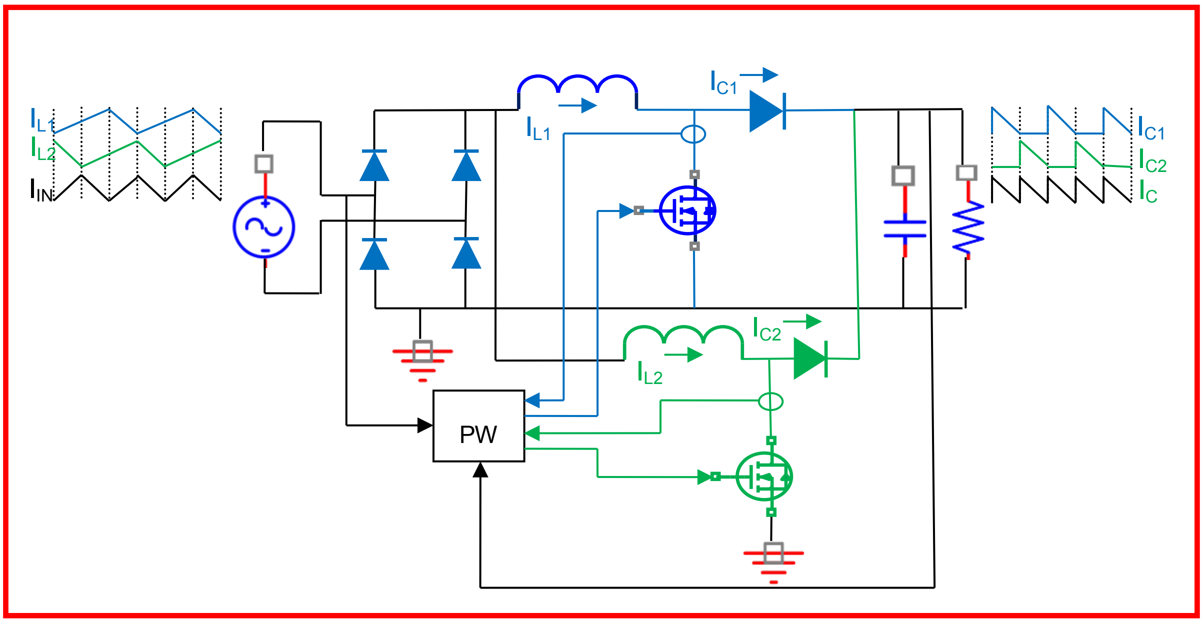

Figure 4: APFC with 180° Phase Shift Interleaved Topology

Phase Management

The interleaved PFC converter topology utilizes two converters to get high performance and efficiency by controlling them with phase shift. Phase management technique used to selectively turn off one of the converters during light loads. During light loads the converter losses remain the same yielding low efficiency. The controller can sense the load, and at appropriate level, one of the phases of PFC converter can be switched off completely. By turning off one phase at lighter loads, efficiency can be optimized over a wider power band. The switching losses of the MOSFETs and reverse recovery losses for the diode remain constant irrespective of load. In most applications in the light load operation, one phase of the converter can deliver the load. Under these conditions one of the converters can be switched off and eliminate these losses. Figure 5 shows the performance of APFC with phase management.

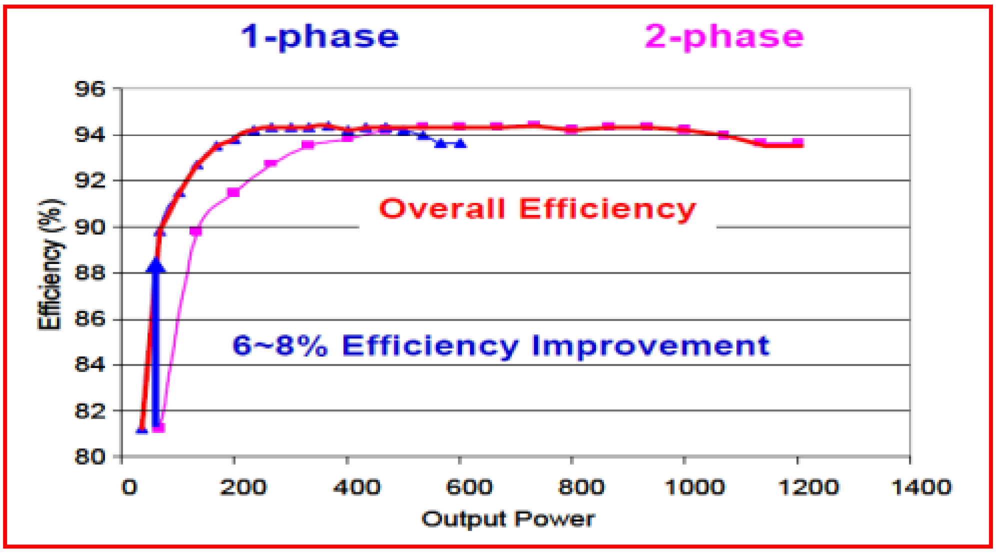

Figure 5: Phase Management

Inverter

A conventional three phase buck inverter is chosen to drive the motor from the DC bus. Motor winding current is monitored by three in-line current sensors. The inverter was designed to protect itself from under voltage, short circuit and temperature rise faults. An MCU controls the switching of the IGBTs in the inverter. The inverter schematic is shown in Figure 6.

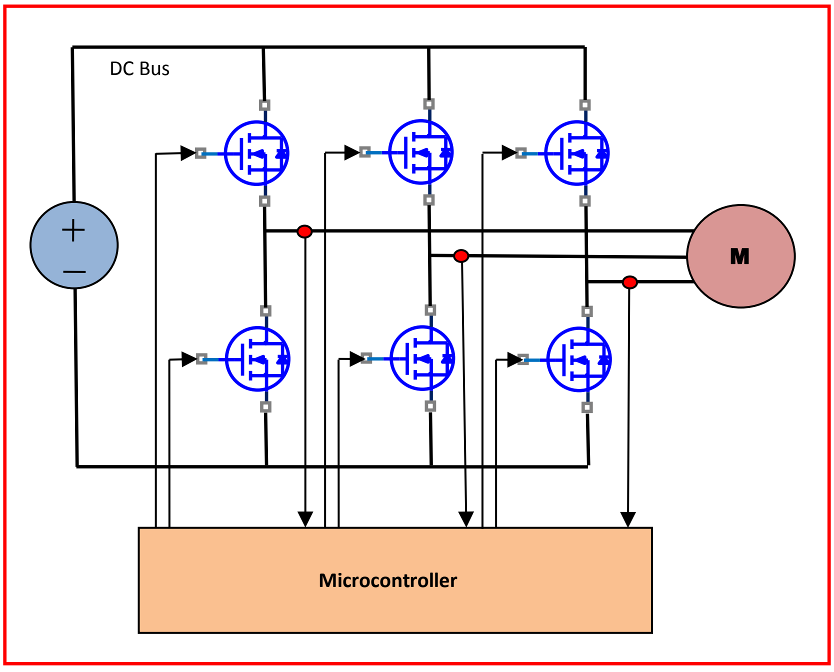

Figure 6: Three Phase Inverter

Motor

We used a four pole Interior permanent magnet (IPM) motor using high-energy Neodymium magnets. The BLDC motor is designed to deliver higher efficiency at elevated temperature with chemical compatibility in refrigerant and oil in a hermetically sealed environment.

The motor was tested on a dynamometer and in a piston type compressor. The test results had shown that the motor efficiency of 96% at rated operating conditions.

Control System Software

Overview

In the end application the motor will be installed inside a hermetic compressor. The motor (stator and rotor both) will be flooded with refrigerant. Any rotational sensor that could withstand the corrosive refrigerant is expensive. Such sensor arrangements would also incur additional cost to run the control wire through the compressor shell and therefore cannot be utilized. The control algorithm, therefore, must operate in "sensor-less" mode. For maximum efficiency and sensor less operation we chose to use a Field-Oriented-Control system.

The control flow diagram is shown in Figure 7. Motor three-phase currents (I_a, I_b, I_c) are measured by the electronics, read my the microcontroller and fed into a Clarke transform. The Clarke transform outputs two-phase currents denoted I_α and I_β. The following Park transform converts the I_α and I_β with the angle information θ into dq reference frame currents I_d and I_q. A regulator in the d-q reference frame controls voltage output to the motor in the same d-q reference. The regulator runs at a frequency of 8 KHz. This regulator also controls motor speed with a response time of 1 KHz. The inverse park transform uses the θ angle to convert the Vd and Vq command into two phase voltages V_α and V_β. The Space Vector Modulation block includes the inverse Clarke transform to convert two phase voltages to three phase and a Pulse Width modulation algorithm to drive the six power switches connected to the motor terminals.

Rotor position is estimated using a two stage observer ("Sensorless Observer System") to generate accurate position estimates based on phase current and phase voltage. The Sensor-less Observer system outputs an estimated θ used by several other blocks as described above. Finally a state controller manages motor start-up, speed ramping and motor shut down.

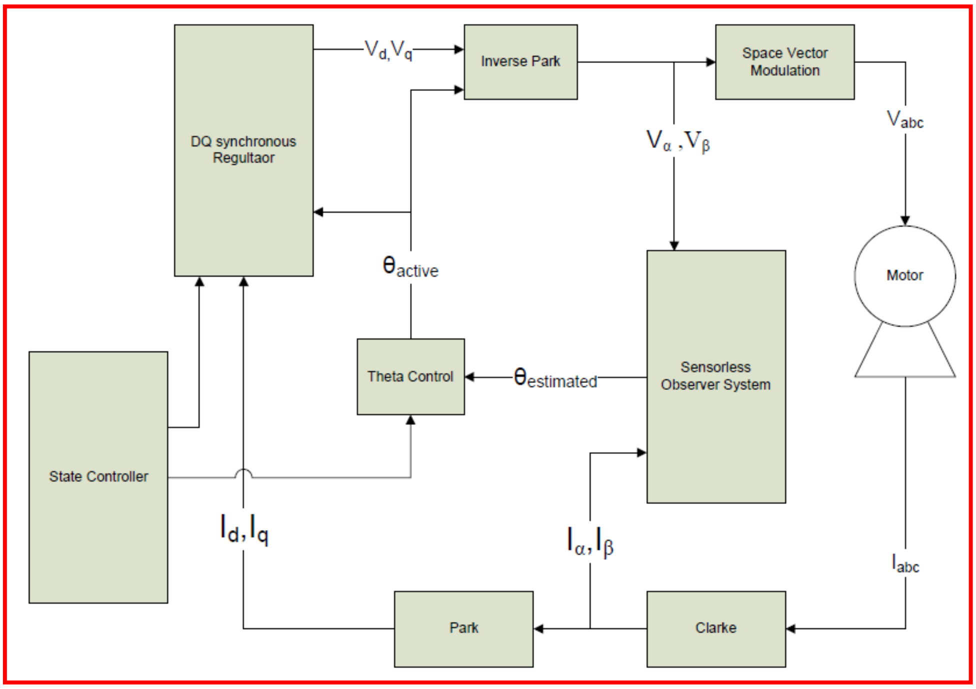

Figure 7: Software Control System Block Diagram

Start up

Ramping the motor speed from 0 to 1200 rpm is accomplished by driving an open loop three phase voltage waveform. The amplitude and frequency of the voltage waveform are ramped up uniformly during this period. At the target switch over speed of 1200 rpm, the frequency and amplitude remain constant. The state controller then manages the switch over from open loop to closed loop control.

Current regulation with pulsing load

The two-piston torque profile is shown in Figure 8. There are two complete and extreme cycles per motor mechanical revolution. To keep up with dynamic loads and the varying piston load profile the position estimator runs at a 2KHz rate.

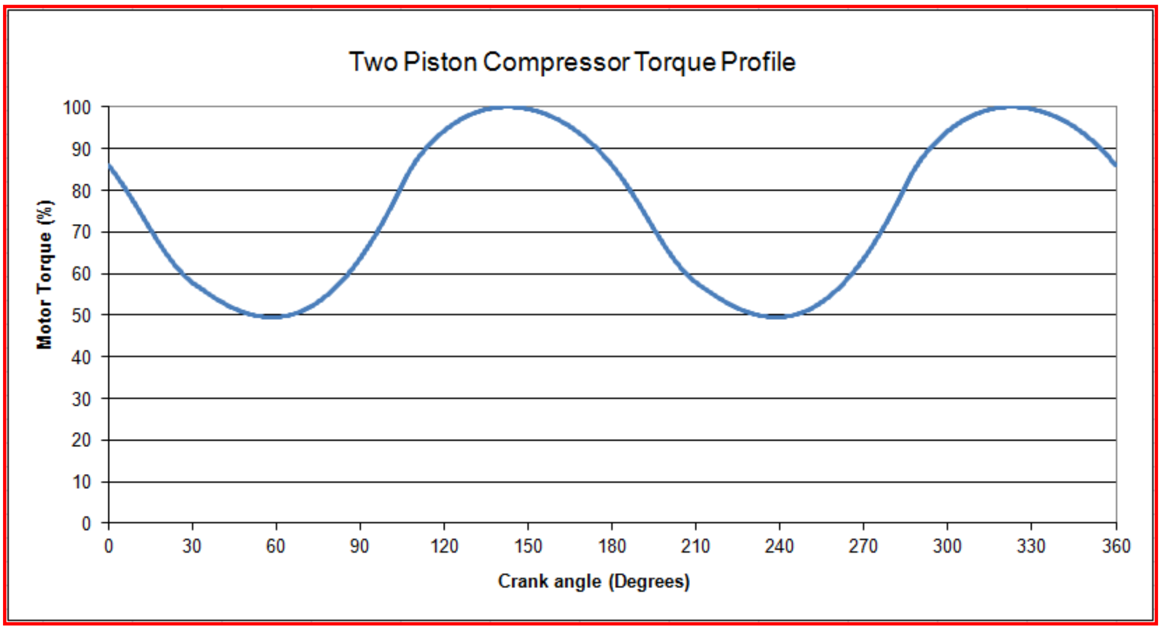

Figure 8: Two Piston Compressor Torque Profile

Regulation and relationship to noise

The speed regulator runs as part of dq frame regulator as seen in Figure 7. Speed was initially regulated quite tightly with an update rate of 2 KHz and optimized control loop constants. To maintain constant speed our torque output oscillated from 50-100% twice each revolution. This pulsating torque caused the compressor to vibrate and generate excessive noise. By de-tuning (slowing response) of the speed and current control loops we were able to mitigate noise.

System Performance

Physical Implementation

A development drive used for initial testing and qualifications shown in Figure 9. This platform includes an eight channel analog diagnostics module used to develop the control algorithms and do initial testing of the output. Configurable analog circuit sections and digital data output circuits are also included.

Figure 9: Development Drive

A compact 6 KW drive was also built and subjected to drive level and system level testing. The picture of the drive is shown in Figure 10 for reference. The drive with motor was tested on dynamometer for various torque levels and speeds to evaluate the drive performance. The drive was also tested running a two piston compressor in the laboratory.

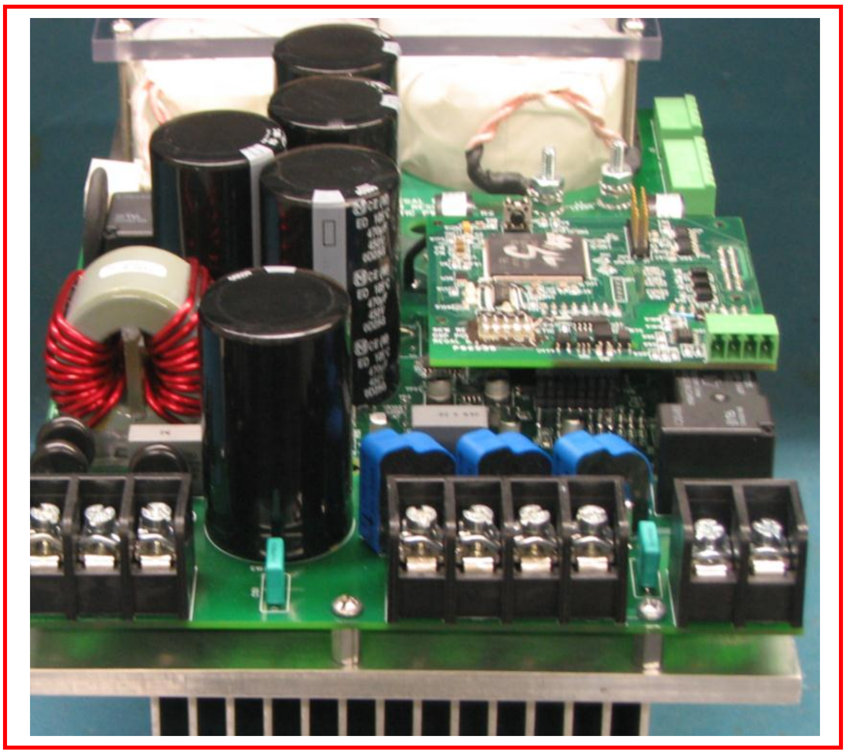

Figure 10: Completed Drive Assembly

Test Setup and Results

Test setup with compressor is shown in Figure 11. The compressor (lower left) is connected to a refrigerant system (410A) capable of reproducing all operating conditions seen in field installations. Our development platform drive is shown in the lower right. Drive efficiency and power factor data was collected with a Yokogawa 3000 power analyzer. A Yokogawa DL850 (to the right of the top shelf) was used to display live data from the control software with actual measurements of current and voltage. With this test configuration we can measure EER data points and compile a complete SEER rating.

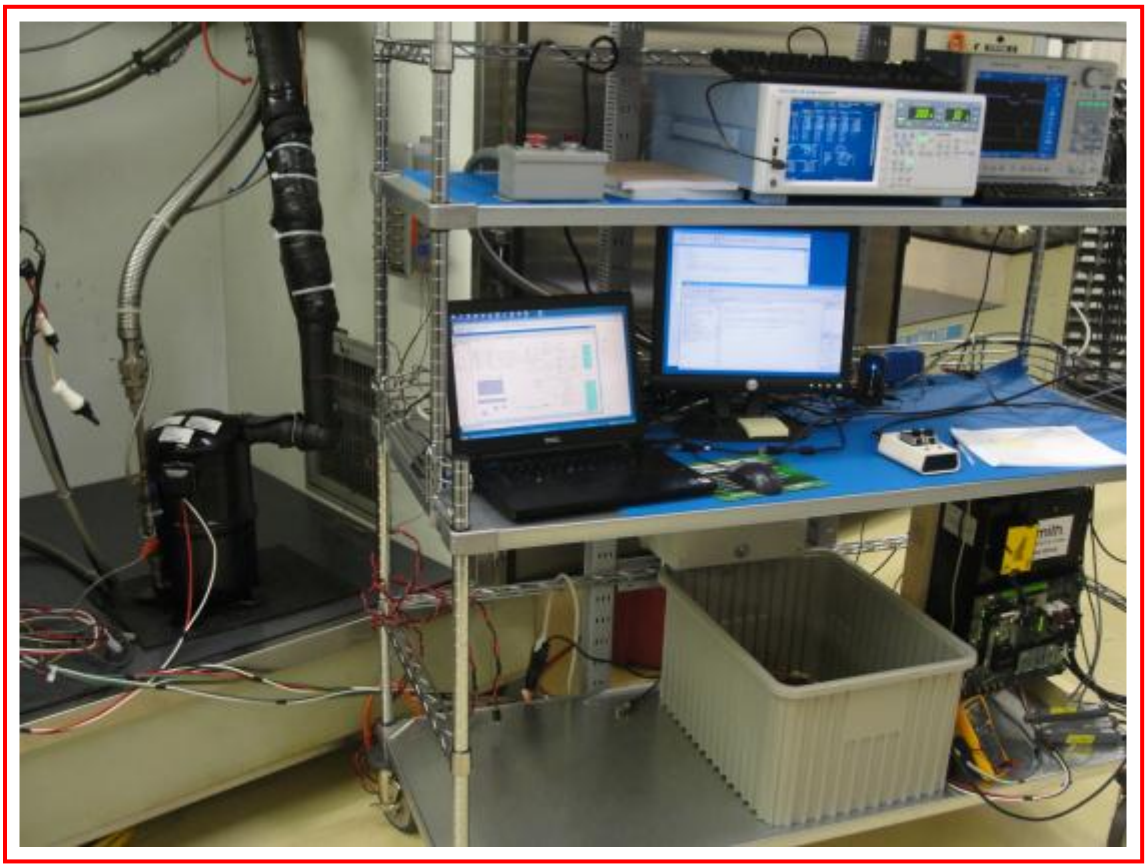

Figure 11: Test setup with compressor

The drive was tested on a dynamometer at various torque levels to verify the performance. A Yokogawa 3000 power analyzer was used to measure power factor, voltages and currents to evaluate the drive performance. The performance curves are shown in Figure 12 for power factor and Figure 13 for system efficiency.

Figure 13 presents final optimized motor and drive performance. Motor and drive contributions to system efficiency are close to balanced in the fully loaded (normal operation) range. Total system efficiency (as defined below) just exceeds 90% over a range of normal operational loads.

With Power input and output defined as follows:

P_{in} = Power input from utility

P_{out} = Shaft Power

Efficiency of the system is defined in % as:

$$Efficiency\ (\%) = \frac{P_{in}}{P_{out}} \cdot 100\%$$

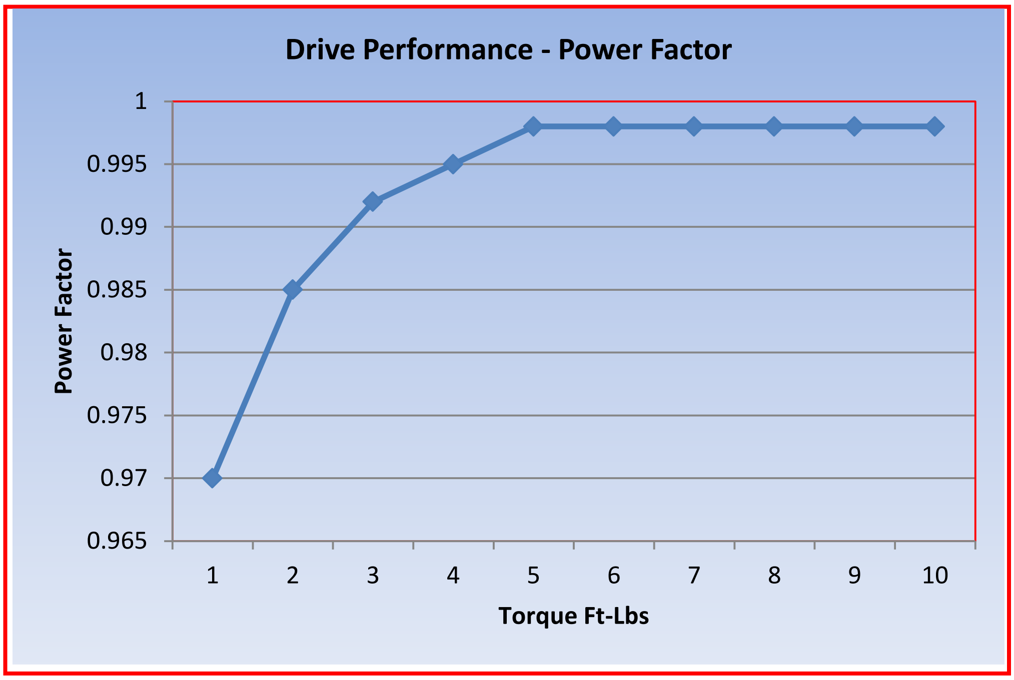

Figure 12: Power factor at various loads

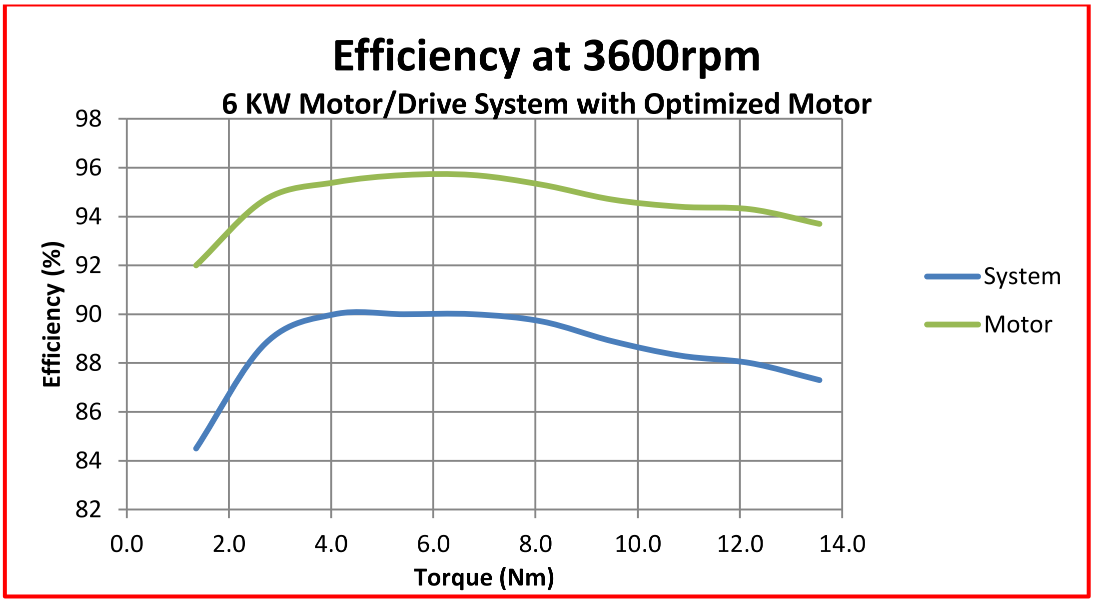

Figure 13: Motor and system Efficiency

Summary and End-Application Efficiencies

A comparative study was conducted to find the effect of adding a PFC circuit to the drive and its impact on the system efficiency. Similar conditions were applied to two drives – one with APFC which is the proposed drive and another drive without a PFC circuit. The data is shown in the Table 1 below. For ease of comparison the input current and power were normalized to 6KW resistive load. It is clear from the data under different load conditions EER values are very close while there is a 35% increase in input current with non-PFC drive.

Table 1: Performance comparison of drives with and without PFC

Drive Name	Input Current (normalized)	Input Power (normalized) %	Power Factor	BTU	EER
Drive – PFC	1.01	100	0.997	49644	8.2
Drive – No PFC	1.37	100	0.726	49828	8.3
Drive – PFC	0.64	60	0.997	70316	18.3
Drive – No PFC	0.90	60	0.701	69612	18.3
Drive – PFC	0.27	25	0.992	44051	27.2
Drive – No PFC	0.41	25	0.651	43477	27.3

Single phase induction motor driven compressor might be part of a typical system with SEER of 13. 13 SEER is currently the minimum required in the U.S. and is equivalent to a COP of 3.8. With a variable speed compressor the system can be brought up to 18 SEER and with more variable speed components (air movers) a SEER of 20 or 22 is possible. Table 2 shows potential cost saving for a residential application using a 5ton air conditioning system. Costs are totals for one average cooling season. Cost savings are significant, easily reaching $300 per year even in regions with inexpensive electricity. The cost benefits are even greater in areas with higher electricity prices and/or longer cooling seasons.

A lot of work was performed and reported by many authors comparing a constant speed air conditioners (CASC) and variable speed air conditioners (VSAC). The study conducted by Ing Youn Chen [4] showed that the comfort for the user is far greater with variable speed air-conditioner than the constant speed air-conditioner as the variation of temperature around a set point is 0.4°C in the case of VSAC verses 2°C for CSAC. It has been reported that while the user comfort is increased with VSAC, the power consumption is reduced installing VSAC as compared to CSAC. In another study conducted by Florida Solar Energy Center “Measured Energy and Peak Demand Reduction from High Efficiency air Conditioner Replacement” by John A. Masiello and Mathew P. Bouchelle of Progress energy Florida, Inc and Danny S. Parker and John R. Scherwin of Florida Solar energy Center [1] had shown an average energy saving of about 50% when SSACs were replaced with high efficiency VSAC equipment. The study was conducted over a long period to cover all four seasons to evaluate the differences in energy consumption and user comfort properly and conclusively. Apart from savings in energy consumption the study also found a significant reduction in peak demand by about 35 – 50%.

From various studies and published data it is very clear that variable speed air handling systems provide more comfort to the consumer at reduced energy cost. Along with the consumers, utility companies are also benefited from the variable speed air handlers with reduced peak demands.

In Table 2 below as shown, there are significant savings to be realized in systems using this type of variable speed compressor. In addition, our drive does not degrade the power factor of the end system maintaining low losses and an optimized electric power distribution system.

Table 2: Typical Air conditioning Systems Cost

EER (BTU per Watt hour)	COP (Coefficient of Performance)	Power Consumed (Kwh)	Electricty Cost ($0.20 Per KWh)	Savings (Compared to 13 SEER)
13	3.8	3846	$769.23	$0.00
18	5.3	2778	$555.56	$213.68
21	6.2	2381	$476.19	$293.04

Conclusions

The need for improving the efficiency of HVAC systems has been imposed by various government agencies for energy conservation and to improve user comfort level. With this as background a HVAC system using reciprocating compressor and variable speed electronic drive has been demonstrated with experimental system results.

The design methodology for the drive electronics to achieve near unity power factor and high system efficiency (90%) has been illustrated and experimentally demonstrated in a 5 ton compressor system. Unity power factor can be achieved without significantly reducing motor drive efficiency.

A comparative study is conducted and presented between the existing fixed speed drives and variable speed drives as proposed in the literature and benefits of such a drive in the light of current government regulations has been demonstrated.

The design for the drive electronics has included necessary frame work for easy adaptation to meet interface requirements of various system controllers and agency requirements including forthcoming smart grid devices.

References

[1] "Measured Energy and Peak Demand Reduction from High Efficiency Air Conditioner Replacement", John A. Masiello and Matthew P. Bouchelle; Progress Energy Florida, Inc. Danny S. Parker and John R. Sherwin, Florida Solar Energy Center

[2] U.S. Energy Information Administration, www.eia.gov, "Residential Energy Consumption survey (RECS)", 2009

[3] "ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment". Air Conditioning, Heating and Refrigeration Institute. 2008.

[4] Ing Youn Chen, 2009: A comparative study between a constant speed air-conditioner and a variable speed air-conditioner. (Report) ASHRAE Transactions – January 1, 2009

[6] Burns, R. and Hough, R. E., 1991. Monitoring and Evaluation of Rplacing Low-EFFICIENCY Air Conditioners with High-Efficiency Air Conditioners in Single-Family Detached Houses in Austin, Texas, ORNL/Sub/86-SA566/V, Oak Ridge National Laboratories, Oak Ridge, TN.

[7] Neal, L. and O'Neal, D. "The Impact of Residential Air Conditioner Charging and Sizing on Peak Electrical Demand," 1994 ACEEE Summer

Study of China Variable Speed Air Conditioner: Energy Efficiency, Life-cycle Cost and Impacts of Subsidy Program

ZHAO Feiyan, HU Bo, ZHENG Tan, LI Jiayang, ZENG Lei

Abstract:

Sales of variable speed room air conditioners (AC) in China reached 25 millions in 2011, expanding from 10% to 42% of all the ACs in only 5 years.

This development was supported by a series of national policies: a MEPS (Minimum Energy Performance Standard) for variable speed ACs was implemented in 2008, followed by an energy label in 2009, and the national energy efficient product subsidy program since June 2012.

This paper is based on retail market data gathered in the framework of the MACEEP study ("Market Analysis of China Energy Efficient Products" study led by Top10 China and CLASP (Collaborative Labeling & Appliance Standards Program). The data cover the ACs' energy related properties such as SEER (seasonal energy efficiency ratio), cooling and heating capacity and power, cooling season consumption and purchase price for end-consumers.

The cooling capacity is the crucial property, which influences also the heating capacity, the SEER, energy efficiency tier and retail price. The energy efficiency tier is the key element regarding the MEPS, label and subsidy. The market shares according to tiers show that revising MEPS and label is urgently needed to promote the market transformation.

Based on the retail price and electricity consumption, the life cycle cost and payback time of the high efficient products can be calculated. The results show that the subsidy program and other incentive policies should be improved to help the expansion of the high efficient conditioners.

1 Product background

1.1 Market status

The variable speed air conditioners were introduced to the Chinese market in the 1990s. The sales remained low with slow growth rate up to 2009. In 2010 and 2011, the sales doubled over each of the previous years and the market share rapidly expanded from 16% in 2009 to 35% in 2011. The growth rate of sales plateaued in 2012, but the market share of the variable speed air conditioner increased to 44%, which was resulted from the significant decline in the sales of the fixed speed air conditioner.

1.2 Energy efficiency standard and label

The first energy efficient standard for variable speed air conditioner - GB 21455-2008, was implemented in September 2008 and hence covered by China Energy Label Program in March 2009. The implementation of efficiency standard and energy label contributed to the rapid expansion of the market share of the variable speed air conditioners.

GB 21455 - 2008 adopts SEER as its main energy efficiency performance indicator. SEER is calculated according to the testing results under maximum and half load operating conditions and the cooling season operating time, which is 1,136 hours. The MEPS has 5 tiers and only sets the requirements for the cooling function (not for heating).

Table 1-1 Minimum efficiency requirements of tiers in GB 21455 – 2008 Unit: [W*h/(W*h)]

Cooling capacity range (W)	Tier 1 SEER requirement	Tier 2 SEER requirement	Tier 3 SEER requirement	Tier 4 SEER requirement	Tier 5 SEER requirement
CC≤4500	5.20	4.50	3.90	3.40	3.00
4500<CC ≤7100	4.70	4.10	3.60	3.20	2.90
7100<CC	4.20	3.70	3.30	3.00	2.80

1.3 Subsidy program

The variable speed air conditioner was included in the subsidy program from June 2012. Comparing to the same cooling capacity with the fixed speed air conditioners, the variable speed air conditioner receives more subsidy, which helps its market penetration.

Table 1-2 Subsidy for Variable Speed Air Conditioner Unit: RMB

	CC≤2800	2800<CC≤4500	4500<CC≤ 7100	CC>7100
Tier 1	300	300	350	400
Tier 2	240	240	280	330
Tier 3	0	0	0	0
Tier 4	0	0	0	0
Tier 5	0	0	0	0

1.4 Data information

The main performance and energy efficiency related properties analyzed in this paper are listed below. All the analysis will be performed based on the market data of those properties.

- Cooling capacity (CC)
- Energy efficiency tier (EET)
- Seasonal energy efficiency ratio (SEER)
- Price
- Heating capacity (HC)
- Co-efficiency of the performance (COP)

2 Product analysis

2.1 Product types and market distribution

Variable speed air conditioner has two types of products – wall mounted and free standing. The wall air conditioners have over 2/3 shares of the market. Besides the traditional cooling function, consumers have become accustomed to the heating function. About 97% of variable speed air conditioners on the market have the heating function.

It is discovered that many models have cooling capacity between 2400W and 2700W. The products are classified by their cooling capacities in 4 groups as shown in Table 2-1.

Table2-1 Variable speed air conditioner product groups

Product group NO.	Cooling capacity range (W)	Number of product models
1	CC≤2800	315
2	2800<CC≤4500	379
3	4500<CC≤7100	174
4	7100<CC	136

4500W is the point of distinction in cooling capacities between the wall and standing conditioners. Very few wall air conditioners have cooling capacity of 5000W or higher.

The heating capacity has the similar distribution pattern with the cooling capacity. 3600W and 4300W are the most popular heating capacities among variable speed air conditioners. The cooling and heating capacities are closely correlated with a coefficient of correlation of 0.873. In general, heating capacity is slightly higher than cooling capacity.

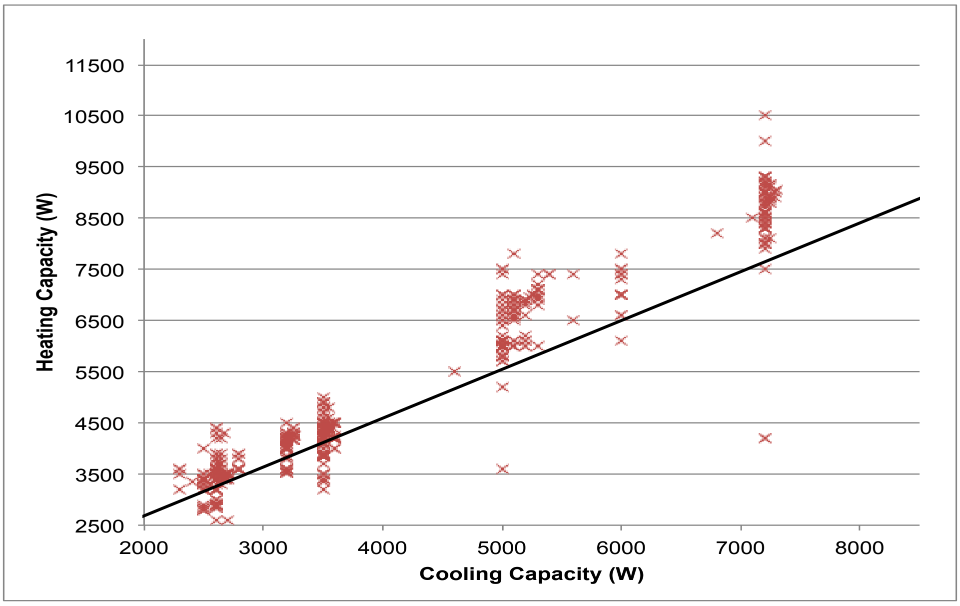

Figure 2-1 Correlation between the cooling and heating capacities

2.2 Energy efficiency

2.2.1 Energy efficiency tier distribution

The current energy efficiency tiers distribution is shown in Figure 2-2. The tier 5 products are almost eliminated from the market, while tier 1 products only occupy a small percentage of the market. Tier 3 dominates the market with over 50% market share. The total percentage of the energy efficient air conditioners (tier 1 + tier 2) is 31.3%, which is higher than normal percentage (20%~25%) of the energy efficient products among other appliances.

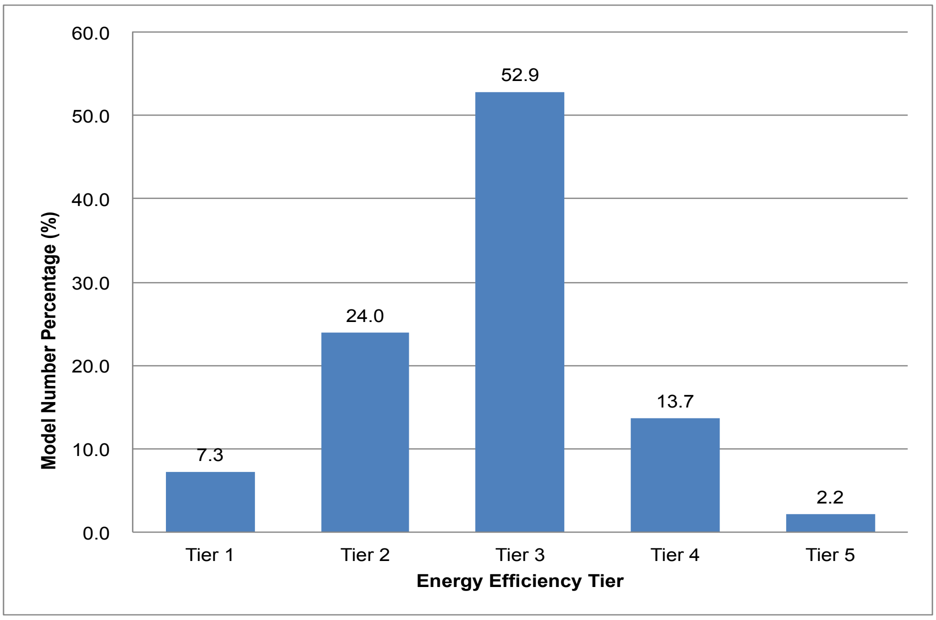

Figure 2-2 Variable speed air conditioner energy efficiency tiers distribution

2.2.2 Seasonal energy efficiency ratio (SEER)

GB 21455-2008 adopts seasonal energy efficiency ratio as the efficiency indicator. Most products have SEERs that are of the minimum requirements of tier 2 and 3. The best available variable speed air conditioner's SEER is higher than 7.

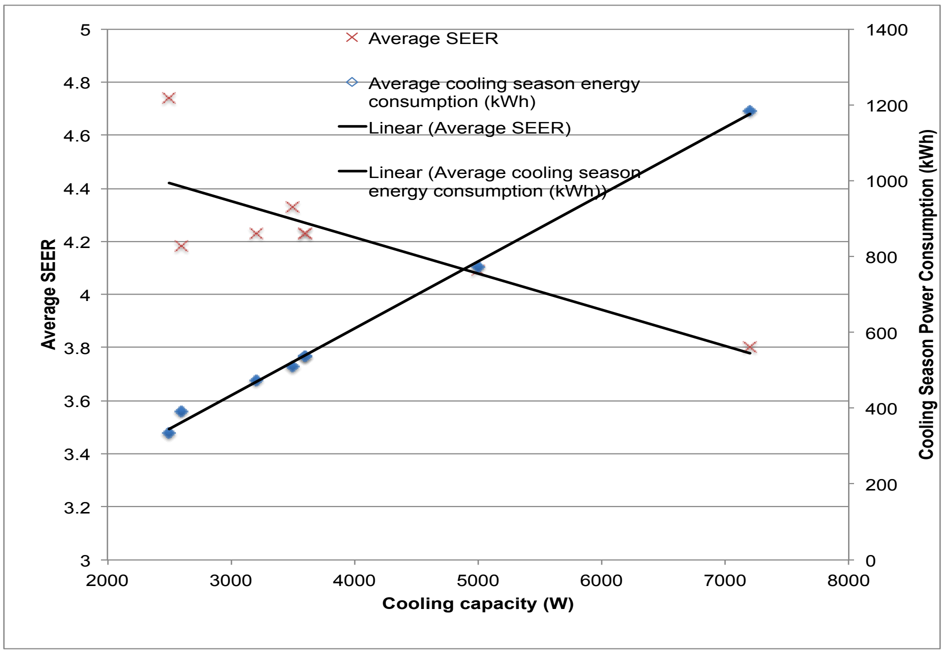

Figure 2-3 Average SEER and cooling season energy consumption

As shown in Figure 2-3, the SEER generally decreases with the increase in the cooling capacity, while the cooling season energy consumption increases proportionally with the cooling capacity in a near-linear relationship.

2.2.3 COP

In GB/T 7725 - 2004 "Room air conditioners", which sets the testing method and defines the performance indicators of the air conditioners, the heating seasonal performance factor

(HSPF) is introduced as the energy performance of the heating function. It is a voluntary indicator declared by the manufacturers. Due to the lack of data of HSPF, COP is calculated based on the rated heating capacity and heating power consumption. It can also indicate the heating energy efficiency of the variable speed air conditioners.

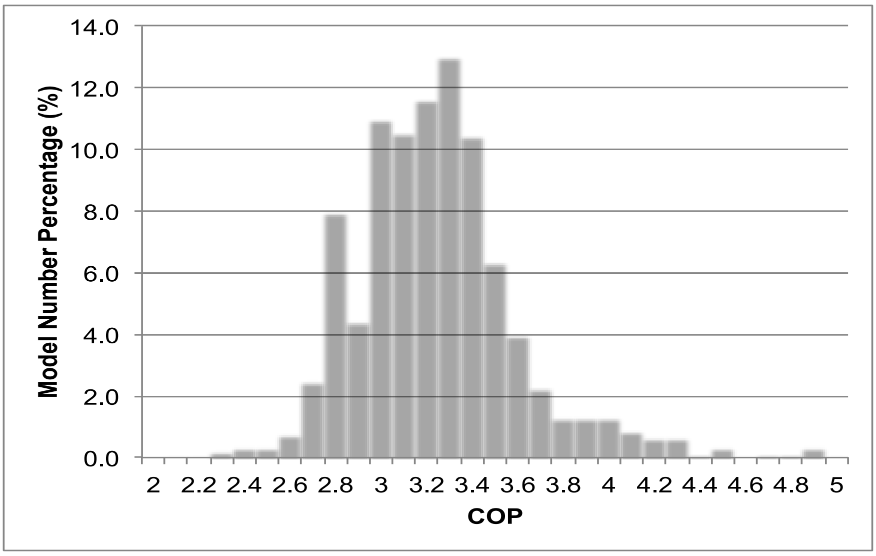

Figure 2-4 COPs distribution

The COPs follows a normal distribution ranging from 2 to 5. Most of the COPs lie within the intervals of 3 to 3.5.

2.2.4 Price

Figure 2-5 shows that the price increases with the increase in cooling capacity. However, the price of air conditioners with cooling capacity of 2500W is much higher than those with cooling capacities between 2600W and 3500W. It can be explained that the average SEER of the 2500W models is much higher than others. This is what the figure shows energy efficiency significantly affects the price of air conditioners with cooling capacities between 2500W and 3500W.

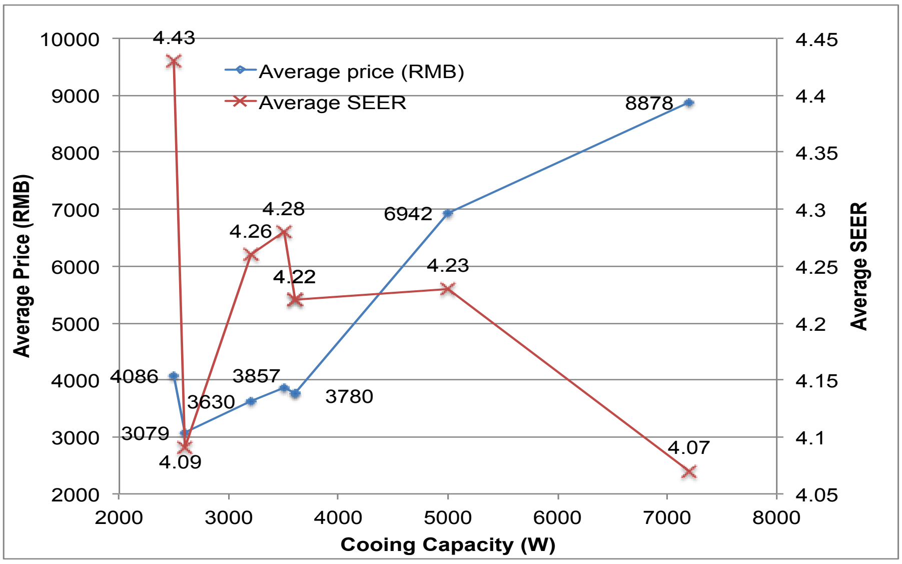

Figure 2-5 Correlation between cooling capacity and price

The subsidy is set based on the fact that the price of the high efficiency products is much higher than the normal or inefficient ones. Figure 2-6 shows the correlation between price and efficiency tiers.

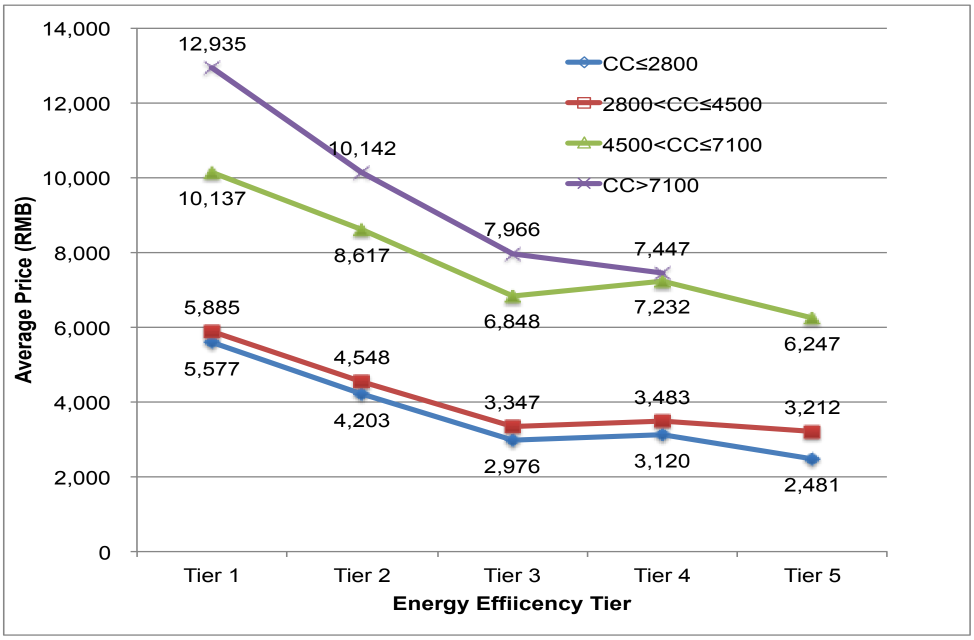

Figure 2-6 Average price of each efficiency tier in four groups

It is evident that the price increases with the cooling capacity. With each product group, from tier 3 to tier 1, the average price increases with the decrease in tiers with a constant rate, especially for the three groups below 7100W. The price differences among tier 3, 4 and 5 are not as big as tier 1 and 2. Products under tier 1~3 can be considered in the same price level, barring some cases where tier 4 and 5 air conditioners are more expensive than those under tire 3. Taking the subsidy into consideration, it cannot sufficiently close or reduce the price gap between tier 1, tier 2 and tier 3 products.

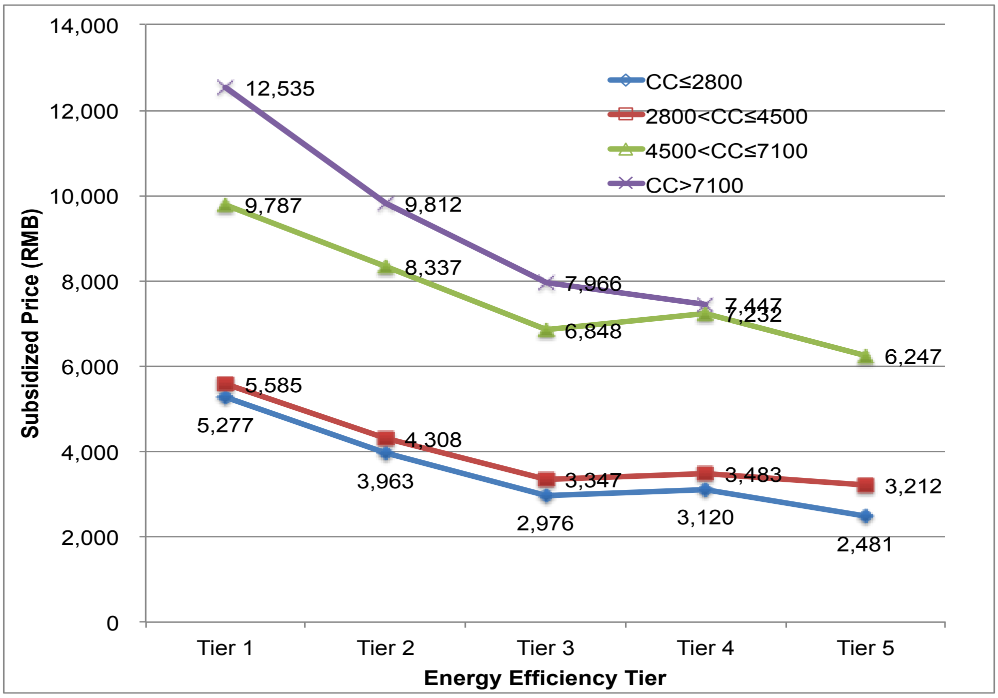

Figure 2-7 Subsidized average price of each efficiency tier in four groups

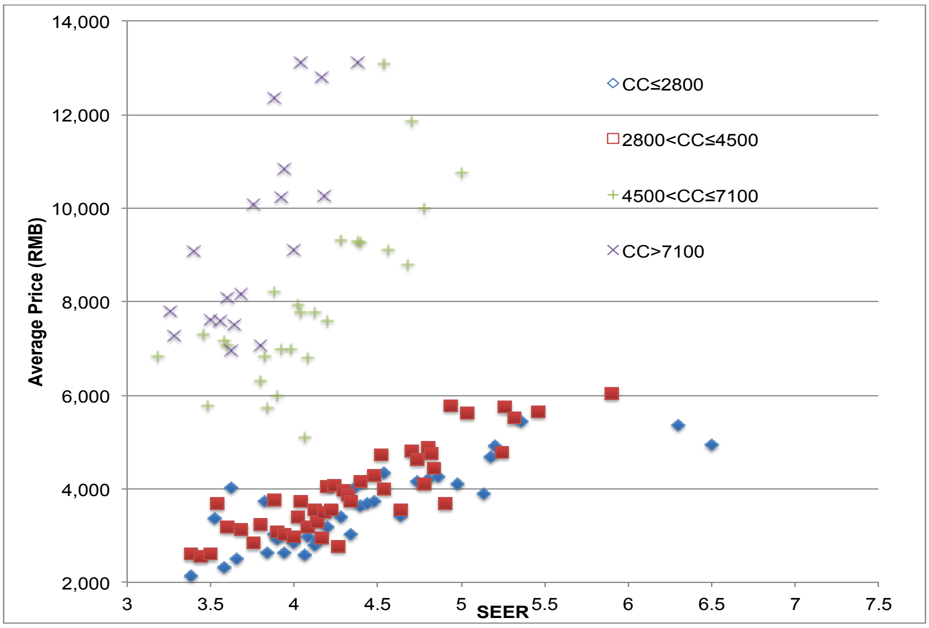

Figure 2-8 Correlation between SEER and average price

Each mark in Figure 2-8 represents the average price of the SEER whose value is calculated from at least 2 samples. In every product group, the similar trend shows that the price increases with the increasing of the SEER, which has the similar trends of the EET-Price.

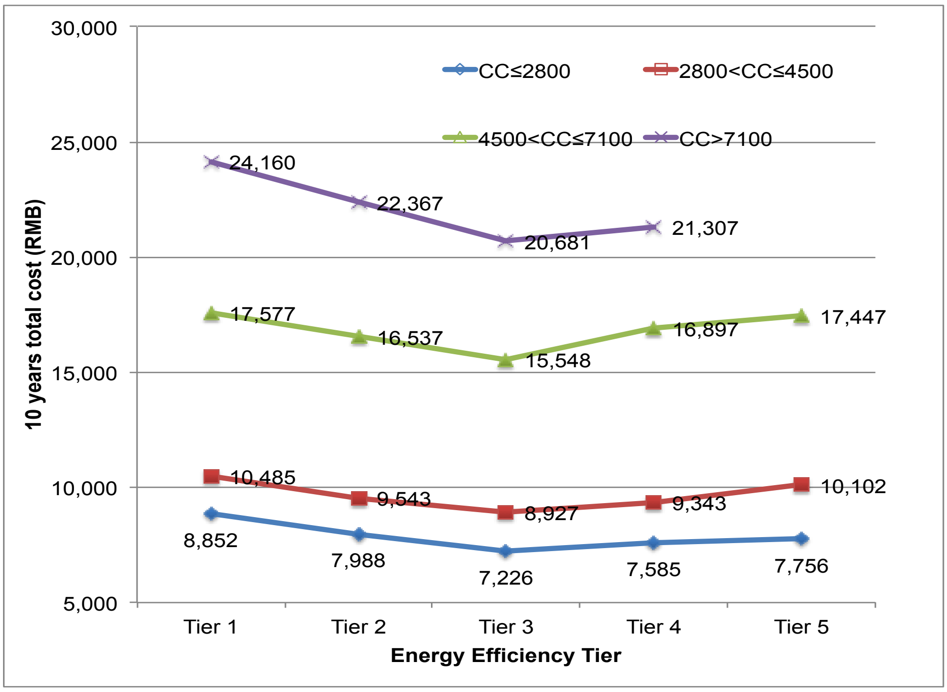

Figure 2-9 10 years total cost of different product groups

Figure 2-9 follows the similar trends with the purchasing price trends. Among all product groups, tier 3 products have the lowest total cost, since tier 3 products have much cheaper price than the tier 1 and tier 2 products. This also indicates that the energy cost savings of high efficiency products cannot offset the high purchasing prices in 10 years time.

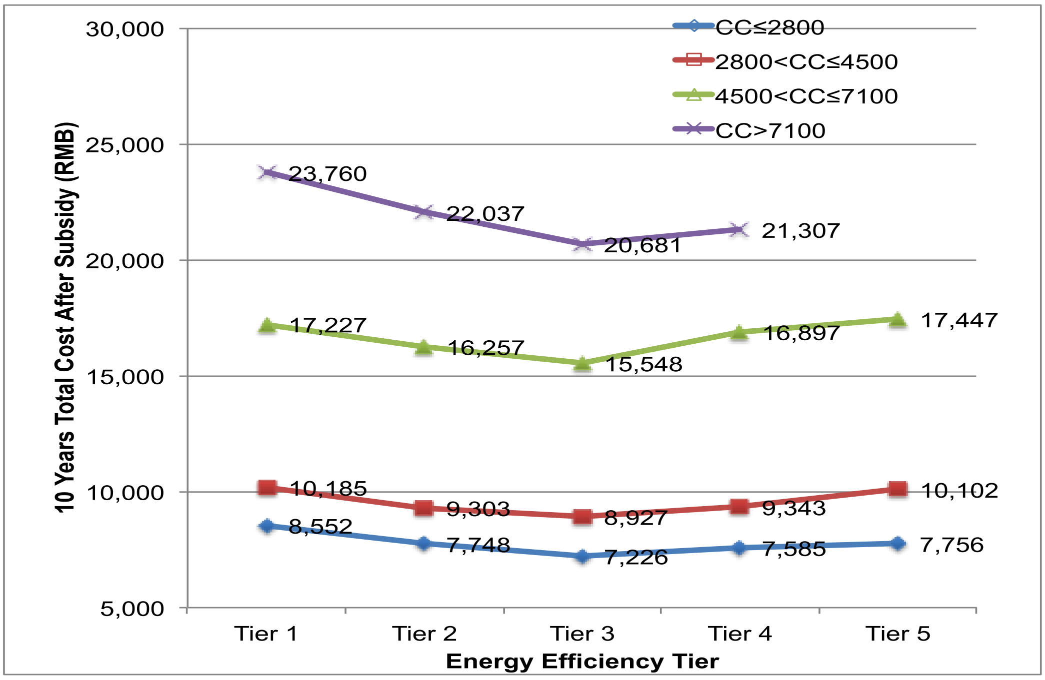

Figure 2-10 10 years total cost of different product groups

Figure 2-10 shows that the subsidy has little or limited impacts on the total cost.

2.3 Recommendations

1. Increase the requirements of the minimum energy performance and hyper energy performances: 1) It has been 4 years since the implementation of the current standard in 2008. It is the time to review and revise this standard. It has been proven that the standard played an essential role in helping the variable speed AC expand its market since 2008; 2) Tier 3 of current standard should be set as the MEPR (Minimum Energy Performance Requirement) in the new MEPS, since the market share of tier 4 and 5 products are already reduced to less than 20%. Based on the experience from the fixed speed air conditioner standard revision, the new MEPS can even use the tier 2 of current standard as its new MEPR, since the variable speed AC has already been included in the new subsidy program. It is well known that the subsidy program phase I played key role in upgrading the fixed speed air conditioner MEPR from tier 5 to tier 2; 3) The average SEER of top efficiency products on the market is much higher than the requirement of tier 1, which means that the manufacturers have the capability to produce products with energy efficiencies much higher than the current tier 1. The requirement of tier 1 should be increased to help these higher efficiency products to distinguish themselves from others.

2. Increase the subsidy and reduce the product models covered by the subsidy program: 1) more subsidy is needed for the high efficiency products in order for them to compete with the normal products in terms of life-cycle cost. The current subsidy is very low compared to the total cost of high efficiency products. In order to close the price gap between higher and lower efficiency products, the subsidy for higher efficiency products should be increased to a point where it is sufficient to affect the decision of the consumers'; 2) subsidy should only be available for top performance products. The existing subsidy program covers both tier 1 and tier 2 products with little distinction. The tier 2 products should be eliminated from the subsidy program and only the top products from tier 1 should be subsidized in order to maximize the impact.

3. Add heating performance requirement to the new MEPS: The COP distribution shows wide range of COPs of the conditioners. The classification scheme of the heating efficiency should be introduced to distinguish high efficiency products from low efficiency products. Users are becoming accustomed with the heating function of air conditioner, as indicated in the study that more than 97% conditioners on the market are with heating function. It was proposed to

include the heating function during the revision of the fixed speed air conditioners MEPS, but the proposal was denied. The latest European standard "Implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for air conditioners and comfort fans" included both cooling and heating functions of air conditioner in the MEPS.

Reference

[1] GB 21455-2008, the minimum allowable values of the energy efficiency and energy efficiency grades for variable speed room air conditioners.

[2] GB/T 7725-2004, Room air conditioners (ISO5151: 1994, Non-ducted air conditioners and heat pumps testing and rating for performance. NEQ).

[3] http://www.etao.com

[4] http://www.sdpc.gov.cn/

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Ground-Source Heat Pump coupled with Thermal Energy Storage

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Abstract:

The GROUND-MED project develops and demonstrates the next generation of geothermal ground-source heat pump (GSHP) systems for heating and cooling in 8 demonstration sites of South Europe.

The project aims at increasing the Seasonal Performance Factor (SPF) of the heat pump installation by using the best components available as well as improved control methods.

This paper presents the preliminary monitoring results of the main performance parameters of a vertical borehole ground source heat pump system installed in a recently renovated administration building, in Coimbra. The installation satisfies the heating and cooling needs of 22 rooms (offices) with an approximate space conditioned area of 600 m^2.

Furthermore, it describes the Phase Changing Materials Thermal Storage System to be coupled to the GSHP, reducing the electricity costs by taking advantage of variable electricity rates while helping the grid to overcome the intermittent output of renewable energy. The Thermal Storage System has a storage capacity of 100kWh.

The paper also recommends possible strategies to further improve the performance of the installation.

Key words: Heat Pump, Ground Source Heat Pump, Energy, Energy Efficiency, HVAC

Introduction

The Coimbra pilot site is included in a broader project aimed at increasing the Seasonal Performance Factor (SPF) of Ground Source Heat Pump (GSHP) installations by using the best components available as well as optimized control methods.

The GSHP is installed in a recently renovated building, with three floors. The GSHP was designed and installed to satisfy the thermal needs of the whole 3rd floor. This is the floor which presents higher thermal gains and losses due to its connection to the roof and due to the large glass area. This floor has 22 rooms (offices) and a space conditioned area of approximately 600 m^2. The same solution could be used for a multi-apartment residential building.

System Description

The system has four main elements: the ground source heat exchanger, the heat pump, the indoor hydraulic loop supplying the fancoils, and the Thermal Storage tank and circuit (not yet installed). A simplified schematic of the system can be seen in Figure 1.

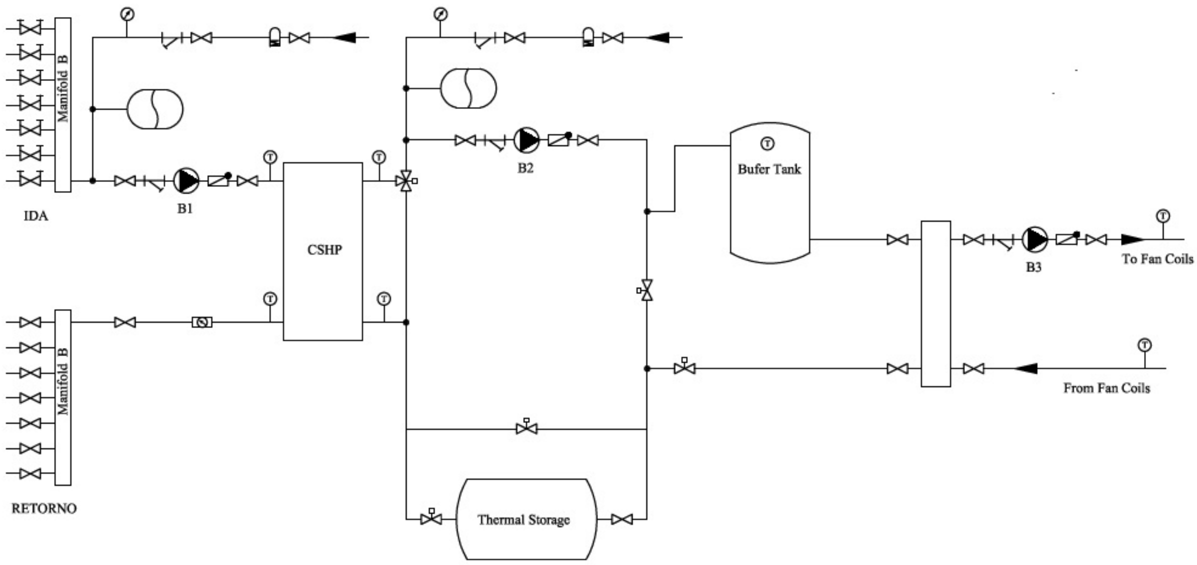

Figure 1. Simplified schematics of the installation

The Ground Source Heat Exchanger (GSHE) consists of seven vertical boreholes connected in a balanced parallel configuration. The seven boreholes are arranged in a 5x5 m rectangular grid. Each borehole is Double-U type and 125m deep.

A prototype water source heat pump of improved seasonal efficiency was developed by CIAT. It is a reversible water to water heat pump with optimized performance. Its key technologies include the next generation of high-efficiency compressors and brazed plate heat exchangers. Reversibility is done on the water side in order to always be in counter current on the heat exchangers. This is achieved by 3-way motorized valves as shown in Figure 2.

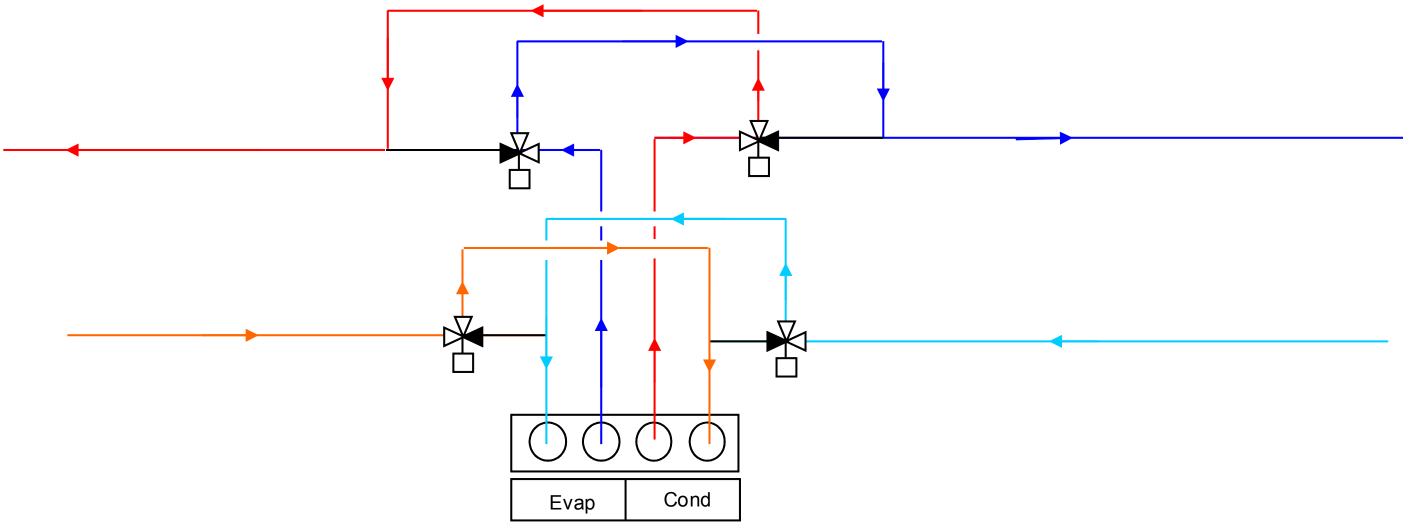

Figure 2. Principle of the water reversibility with 3 way valves

Two networks constitute the indoor loop: the primary network heated or cooled by the heat pump and the secondary network to feed the fan coils units. Separation between two, is made by a decoupling tank and allow separating request and supply. There is also a buffer tank, to increase thermal inertia of the primary network. This additional volume, reduces the on/off heat pump cycles.

Water circulation in the primary and secondary water circuits is ensured by high efficiency, variable speed permanent magnet motor pumps.

The fan-coil units are equipped with high efficiency impellers and high efficiency permanent magnet motors capable of varying speed. Their speed is automatically regulated and decreases as the temperature in the room approximates the user set-point. This greatly reduces the electricity consumption of the fan, which can be as low as 5 Watt.

Additionally, the fan-coil units are designed to operate at a lower temperature – less than 40°C – when in heating mode, and at higher temperatures - 10°C / 15°C – when in cooling mode, than the temperatures normally used in these applications. This approach allows for a considerable improvement in the heat pump performance.

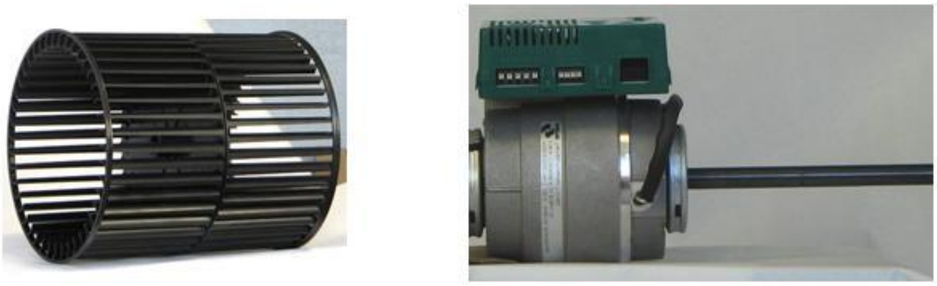

Figure 3. High efficiency impeller and permanent magnet motor

Preliminary Monitoring Results

A Data Acquisition System was developed, specifically for this project, which allows for the monitoring of the system's performance through the collection of all the relevant system variables (heat pump and building). Such a system also allows for the constant improvement of the installation performance.

The next figures present the monitored values of some of the key performance variables of the system for one average heating day.

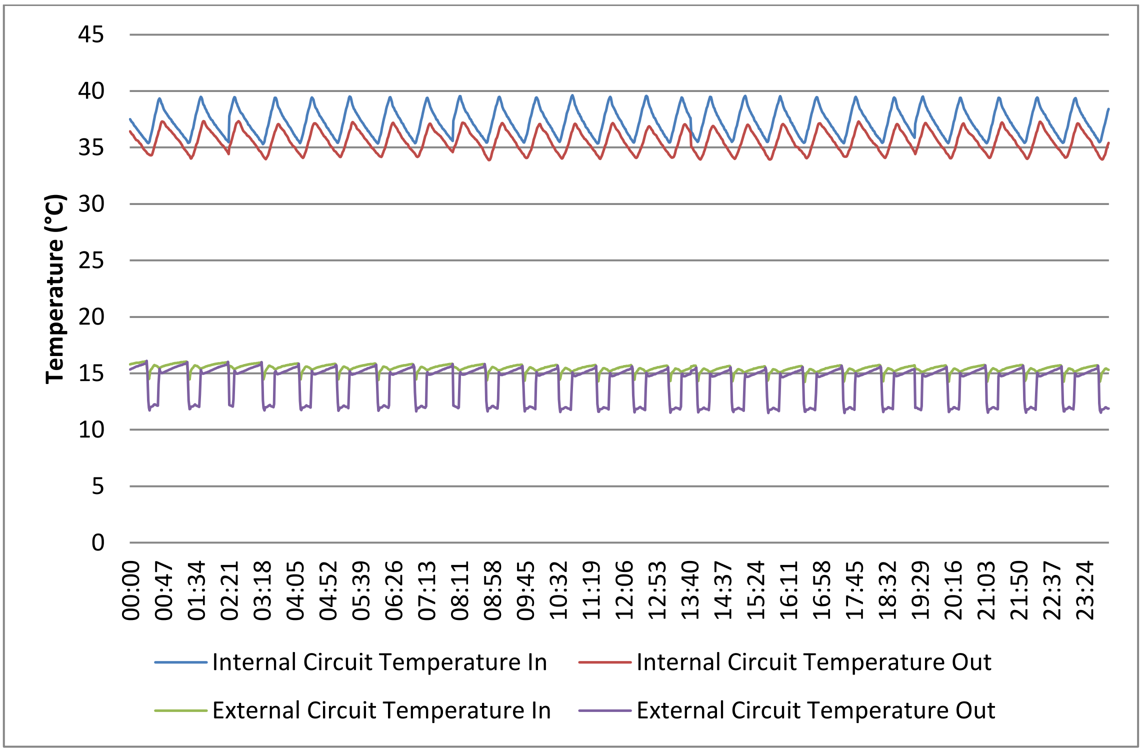

Figure 4. Temperature evolution in the two water loops for one heating day

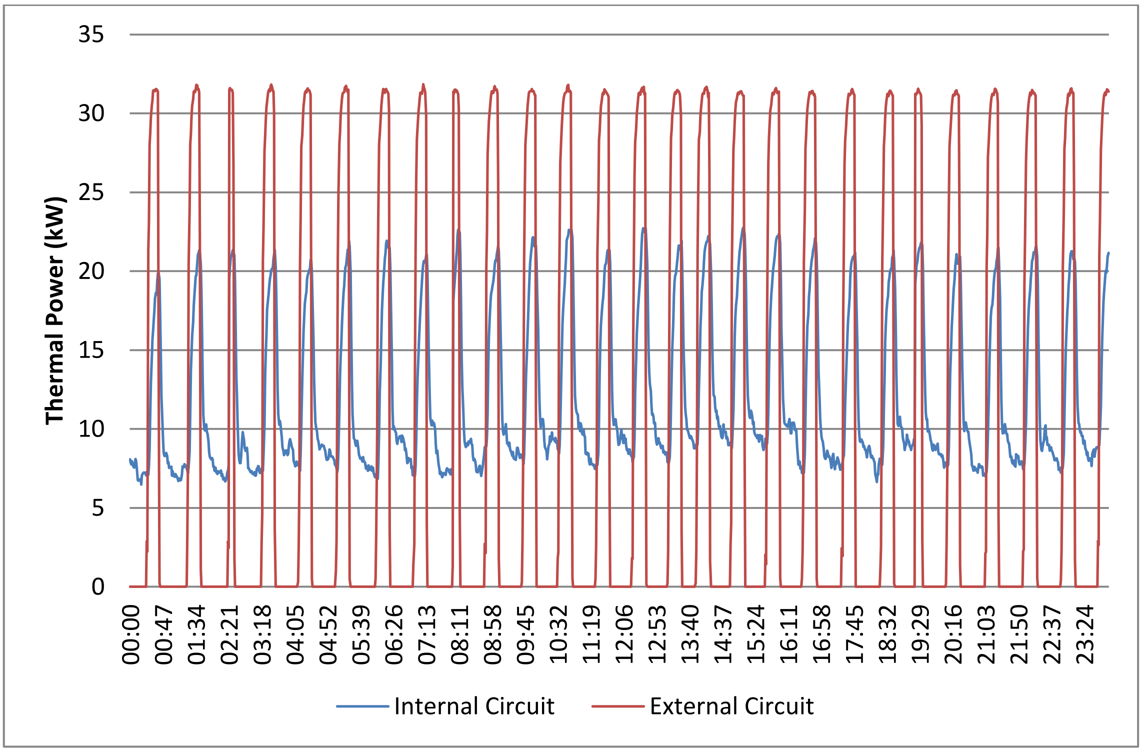

Figure 5. Thermal power for one heating day

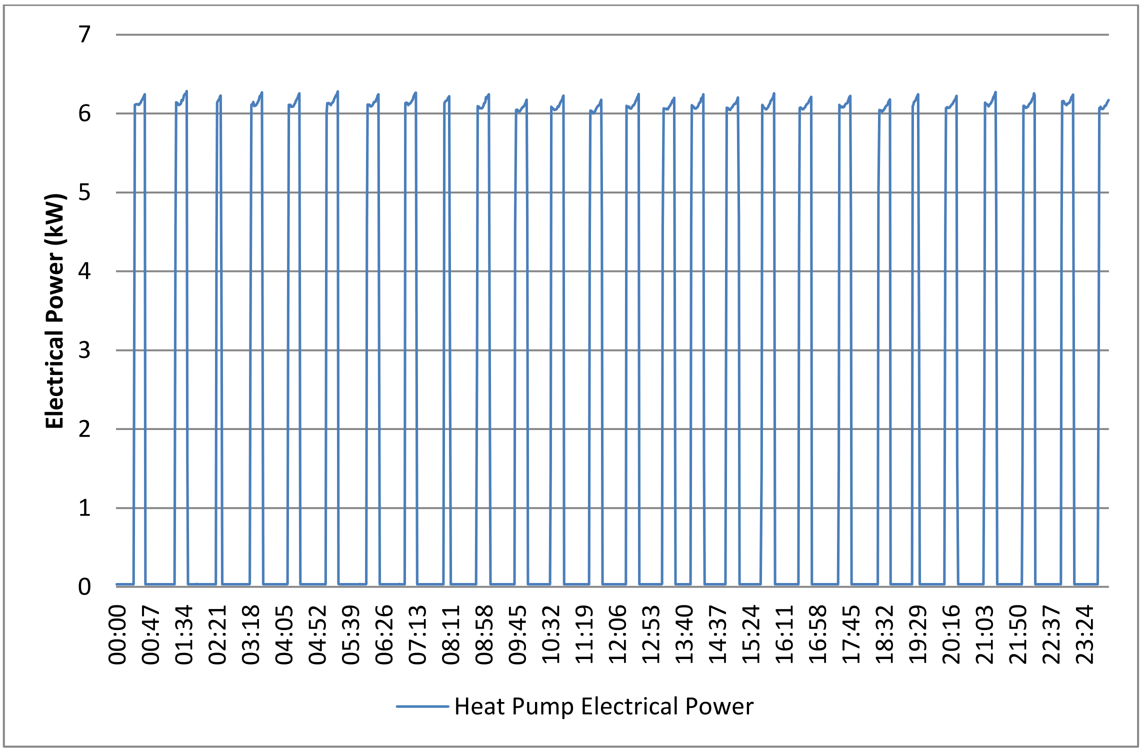

Figure 6. Heat Pump compressor electrical power for one heating day

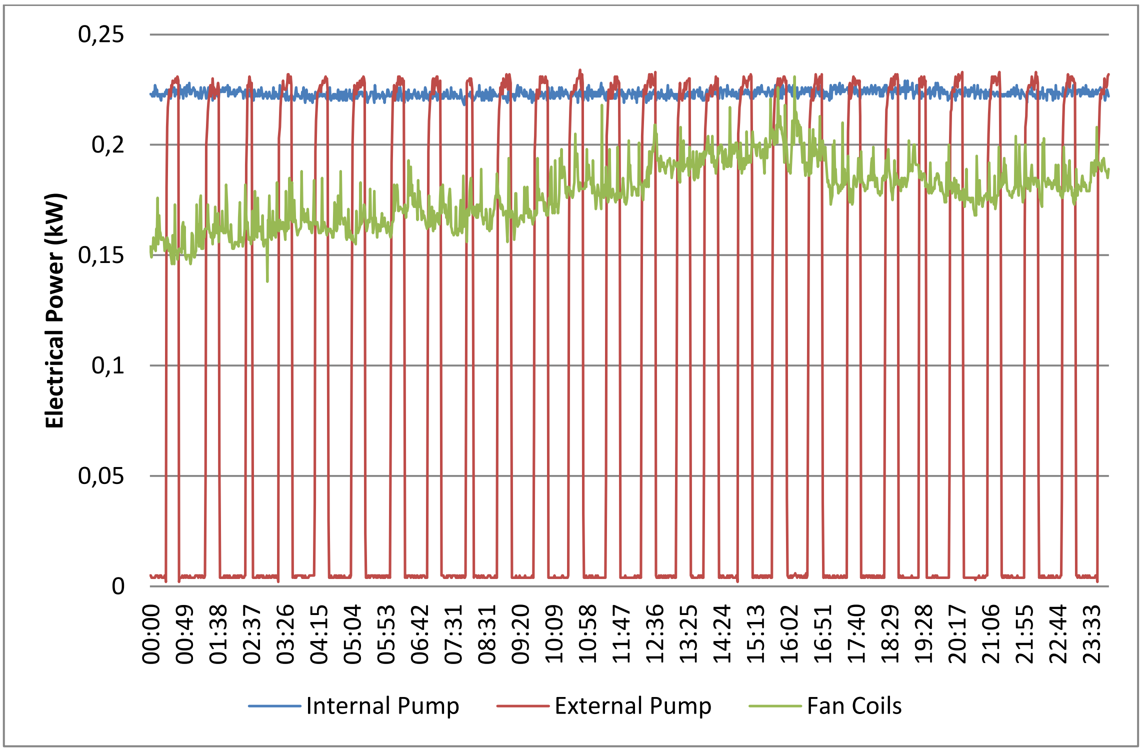

Figure 7. Auxiliary equipment electrical power for one heating day

For the purpose of technology evaluation four different Daily Performance Factors (DPF) values are calculated as follows:

$$DPF = \int_0^t \dot{Q} \cdot dt \Big/ \int_0^t \dot{P} \cdot dt$$

where Q corresponds to the heating or cooling energy supplied to the building and P is the power consumption considered:

- Heat Pump compressors in the case of DPF1,
- compressors and external circulation pump in the case of DPF2,
- compressors and both external and internal circulation pumps in the case of DPF3 and
- compressors, all pumps and fan-coils in the case of DPF4.

Because of limitations in the data collected so far the above values are only shown for one average heating day, in Figure 8.

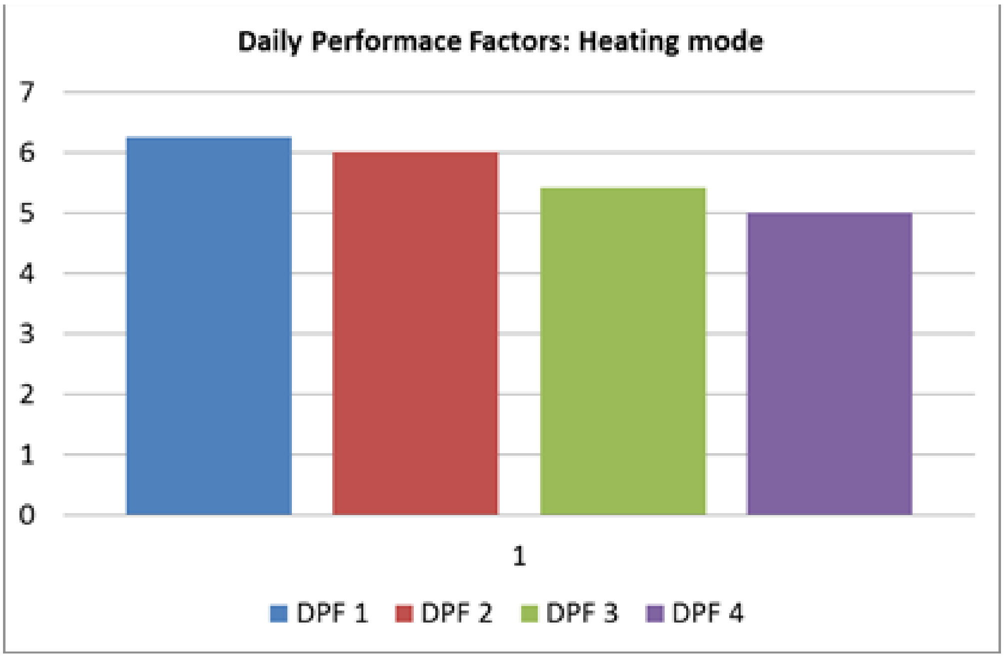

Figure 8. Daily performance factors for one average heating day.

As it can be seen, the performance factors achieved are very high. DPF2, which takes into account the energy consumed by the external circulation pump was improved by restricting the pump to work only when the heat pump is on. Further improvements are expected by optimizing all circulation pumps speed, and consequently the flow rate, according to the thermal demand from the building.

For this purpose, a methodology is being developed by the Polytechnical University of Valencia (Spain) in collaboration with the University College of Dublin (Ireland) and the project partners responsible for the demonstration sites, including the University of Coimbra (Portugal). This methodology allows finding the optimal operating flow for the circulation pumps as a function of the instantaneous thermal load. The advantage of the proposed methodology is that it can be carried out on site and therefore is able to take into account the complex phenomena occurring at the heat pump and the ground source heat exchanger when the flow rates are varied.

Thermal Storage

A latent heat thermal energy storage (LHTES) is planned to be coupled with the already installed system. This will help reduce the electricity costs taking advantage of variable electricity rates while helping the grid to accommodate the intermittent output of renewable energy, which allows for the wider deployment of renewable energy generation in the wider electricity grid. The increasing integration of intermittent nature renewable energy requires the need to consider new ways of managing the grid since this type of supply often does not coincide with periods of increased demand. It is therefore necessary to develop solutions that allow the flexible integration of energy generation with energy consumption if there is to be a shift to more renewable energy generation.

The occupancy period of the building is from 8 AM to 7 PM is made evident by the load profile presented in Figure 9.

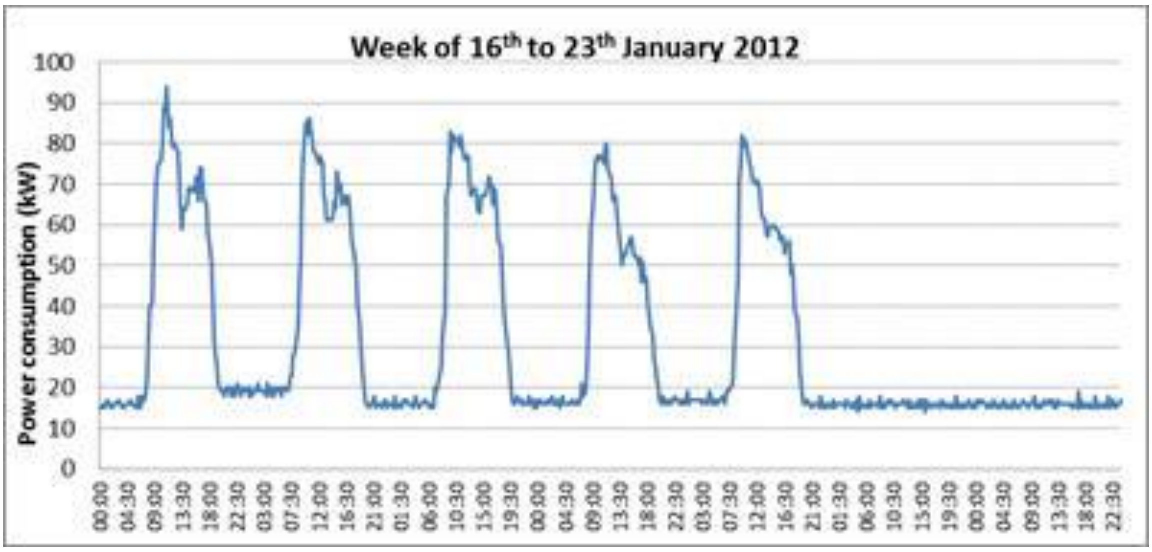

Figure 9. Electrical Load profile of the building – Mid-winter.

As can be seen, the peak load of the building occurs in the morning, when workers turn on all the electric equipment, including the space heating system. This peak load period coincides with the national peak load demand period in Portugal, where electricity and power have a higher price, as can be seen in table 1. The peak period has two penalizing rates, one for the electricity consumption and another one for the power demand.

Table 1: Contracted electricity prices of the building in 1st trimmest of 2013.

Period	Period	Electricity (€/kWh)	Peak Power (€/kW.day)
Peak period	9 AM to 10.30 AM 6 PM to 8:30 PM	0,2124	0,4311
Middle peak period	8 AM to 9 AM 10:30 to 6 PM 8:30 PM to 10 PM	0,1173	
Off peak period	10 PM to 2 AM 6 AM to 8 AM	0,0808	
Special off peak period	2 AM to 6 AM	0,0727	

The use of thermal storage will, therefore, reduce the electricity bill of the building (moving consumption to lower cost off-peak periods) and reduce the peak power.

Energy storage with phase change material (PCM) has numerous advantages over sensible systems. The energy is stored at a relatively constant temperature, and because the required mass and volume of the system are lower energy losses to the surroundings are lower than with conventional systems [1] [2].

The desired operating temperature range is one of the most important criteria for the selection of phase change heat storage materials, since the heat transfer rate and thus the performance of the system mainly depends on the difference between the temperature of the heat transfer fluid and the melting point of the PCM.

Taking into account that the GSHP and the fan coils were designed to operate with a supply temperature of 40°C and a return temperature of 35ºC in the space heating loop and that a delta T of at least 5ºC is needed to charge and discharge the stored thermal energy, the melting point range must be within the range of 44 – 48ºC, ideally 45ºC.

The selected PCM is a hydrate salt (sodium thiosulfate pentahydrate) with a melting point of 46ºC and a heat of fusion of 190kJ/kg. This PCM is already commercially available in rectangular plastic containers that can be stacked on top of each other forming a self-assembled large heat exchanger inside the tank.

Figure 10. PCM encapsulated in rectangular plastic containers [PCM Products Ltd]

The thermal storage capacity was determined based on the estimated thermal load of the 3rd floor, the electricity rates and the cost of the thermal storage system. A full thermal storage strategy would not be cost effective, since in Portugal the heating season rarely exceeds twelve weeks. Therefore, a partial-storage strategy will be used to meet thermal needs during peak periods.

The thermal storage unit consists of a tank, with a total volume of $3m^3$, filled with 400 containers of a Phase Changing Material (PCM) resulting in a storage capacity of 100kWh.

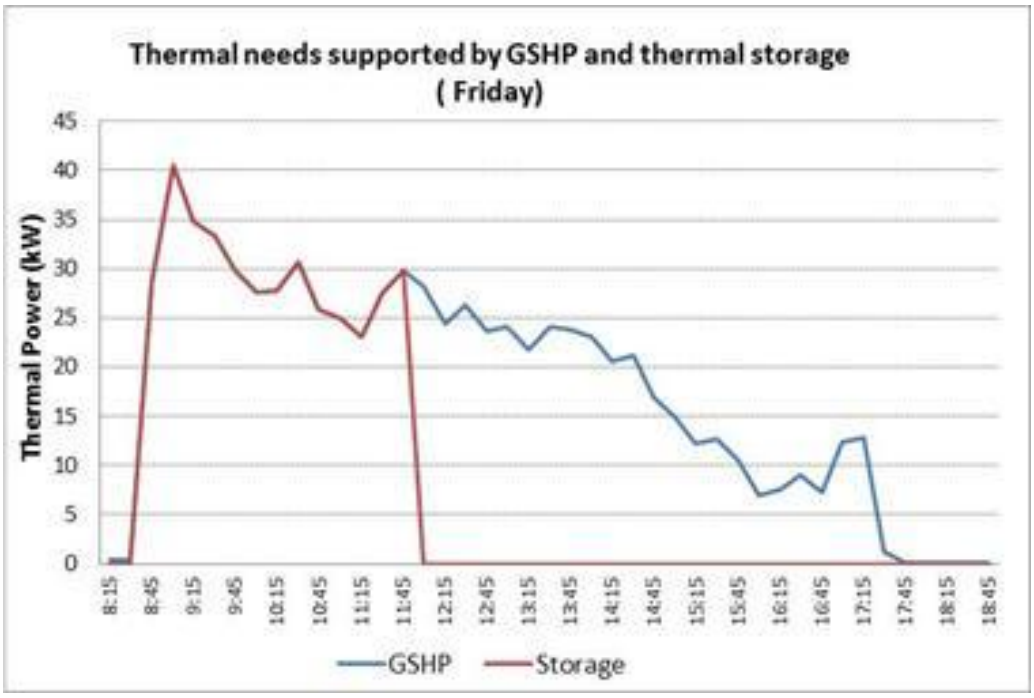

Figure 11. Capacity Storage of 100kwh supports thermal needs during 3,5h

As it can be seen in the previous figures a thermal storage capacity of 100 kWh can support the thermal needs of the 3rd floor during the peak period in a typical cold day. In less cold days in winter the thermal storage may satisfy most of the thermal necessities.

Conclusions

High performance Geothermal Heat Pump systems, such as the one demonstrated here, have the potential of completely replacing the use of diesel oil and natural gas boilers for domestic space and water heating and of reducing electricity consumption for cooling by at least 50%, by replacing old air conditioning systems. The latter occurs, as the SPF of high performance geothermal heat pumps is twice that of split air conditioning units.

Although the GSHP is already a very efficient technology for space conditioning, the addition of a thermal storage may still be an attractive solution leading to additional benefits for the power grid, by reducing peak demand and integrating intermittent sources and for the consumer. In this case study a reduction of around 50% of the electricity costs for space heating during the winter period was estimated.

Most EU countries have large-scale programs to increase renewable electricity generation. The above mentioned impacts will strongly increase if the electricity used in the heat pumps is provided by renewable generation. The use of thermal storage, will contribute to balance the demand for heating with variable renewable electricity supply in a cost-effective way, creating a path towards sustainable heating of buildings.

At the end of this project the demonstration of the combination of both technologies is expected to result in a high efficiency solution for space conditioning, with great potential for replication. It has the additional benefit of using intermittent energy, storing this energy to be consumed when necessary, thereby contributing to a more efficient integration of renewable energies and a more cost-effective operation of the power grid.

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[2] Conference Proceedings: Rousse, D. R., Salah N. B. & and Lassue, S., 2009: “An Overview of Phase Change Materials and their Implication on Power Demand”, Proceedings from IEEE Electrical Power & Energy Conference (EPEC), October 22-23, 2009. Montreal, Canada.

Domestic Refrigeration:
Low climate change impact solution for energy efficiency

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ABSTRACT

On a global basis, the industry, government regulators, and NGOs are continually striving for a low environmental impact energy solution across all energy consuming applications, including household refrigerators. Highly energy efficient blowing agents, in the manner of polyurethane insulation, are a primary solution to climate change impact reduction. This solution outlines the climate change impact imparted from not only indirect contribution, that is, energy consumption, and also additionally, the direct contribution to climate change from the associated raw materials, that is, the global warming impact of the blowing agent, utilised in manufacture of household refrigerators. The solution description characterises the energy consumption performance, the manufacturing impact considerations, and end of life management in the construct of a pro forma life cycle climate performance. Prototype household refrigerator/freezer product, of significant scale, has been manufactured with current commercial household refrigerator platforms, utilising these low environmental impact blowing agents. These refrigerator/freezers were assessed for energy performance under rigorous methodology. Detail of the manufacturing process, materials performance, and quality metrics, compared to baseline, current, commercially available refrigerator product will be discussed.

Key words: energy efficiency; sustainability, climate change impact

DEVELOPMENT SUMMARY

A key raw material in the production of high performance, rigid polyurethane (PUR) insulation foam is the blowing agent. Although many blowing agent technologies are available to the foam formulation chemist, the use of fluorocarbon blowing agents has historically resulted in foams with the highest insulation performance, best physical properties, safest and simplest processing characteristics, and best value in use. The use of fluorocarbon blowing agents began as early as the mid-1950s with the introduction of trichlorofluoromethane, or CFC-11. This blowing agent became the industry standard until the mid 1990s, when concerns over ozone depletion led to the development of a second generation of high performance foam blowing agents, the HCFCs. For the rigid polyurethane foam industry, the most commonly used HCFC was 1,1-dichloro-1-fluoroethane, or HCFC-141b. Although conversion to HCFC-141b reduced the ozone depletion potential of the blowing agent by 90%, subsequent regulation required that these HCFC blowing agents also be phased out and a third generation of high performance blowing agents was developed, the HFCs. The most commonly used HFC blowing agent in rigid polyurethane foam is 1,1,1,3,3-pentafluoropropane, or HFC-245fa. This material satisfied the requirements of ozone depletion regulation while, at the same time, retained the high performance and non-flammability required in many foam applications. In many parts of the world, conversion from HCFC technology to HFC technology is complete while, in certain other regions, this conversion is now occurring.

In recent years, concern over climate change is driving the development of a fourth-generation fluorocarbon, one that meets the requirements of both ozone depletion and climate change regulations, current and anticipated. Honeywell, formerly AlliedSignal, has been the leader in the development of fluorocarbon blowing agents and is now leading the development of this fourth-generation fluorocarbon technology. Honeywell has developed two such fourth-generation products: 1234ze(E) – a gaseous blowing agent and 1233zd(E) – a liquid blowing agent, both of which are non-persistent in the environment. Described in this paper, the liquid blowing agent: trans-1-chloro-3,3,3-trifluoropropene (1233zd(E) - trade named Honeywell Solstice™ Liquid Blowing Agent (LBA), successfully incorporates required environmental properties, while maintaining the non-flammability, low POCP, and high performance characteristics that have differentiated fluorocarbon blowing agents for high performance rigid foam insulation applications. These two fourth-generation blowing agents also find application where a flammable blowing agent is unsafe, too costly to use, or fails to provide the desired foam performance. These new high performance materials, while they contain fluorine, also contain an olefin structure, and are therefore referred to as haloalkenes. Because of the presence of a double bond in the molecule backbone, these haloalkenes are a separate and distinct class of materials from their predecessor HFC materials, resulting in a much shorter atmospheric lifetime than their predecessor fluorocarbons, thereby resulting in a much lower global warming potential, or GWP.

BLOWING AGENT PROPERTIES

Table 1 lists certain, select properties of blowing agents compared to 245fa and other commonly used blowing agents. In order to be successful in the application, the fourth generation blowing agent must satisfy a complex and unpredictable mosaic of properties and performance attributes beyond those listed here. Note that the GWP of Solstice LBA is less than 5, is more than two orders of magnitude lower than that of currently utilized HFCs, and is more than one order of magnitude lower than the present limitations in the EU F-Gas Regulation.

Beyond the excellent insulation performance that Solstice LBA imparts to polyurethane foam, it is distinctly different from hydrocarbon blowing agents in flammability characterization. Solstice LBA shipment, storage, handling, and processing does not require flammability risk mitigation, as is the case with flammable blowing agents such as cyclopentane and certain other flammable blowing agents. Solstice LBA is nonflammable by ASTM E-681 test method and has no limitation on hazards classification. Solstice LBA is further distinguished from cyclopentane and other hydrocarbon blowing agents by the low potential to contribute to ground level smog formation (POCP measure), and the U.S. EPA has proposed to classify Solstice LBA as non-VOC. Flammability and VOC mitigation may contribute significantly to the OEM’s cost of adoption and use and, in certain cases, prohibit their use due to safety considerations.

Table 1. Liquid Blowing Agent Select Properties

Properties	Solstice LBA	245fa	Cyclo pentane	365mfc	141b
Mol. Weight	130	134	70	148	117
Boiling Point					
°C	19.0	15.3	49.3	40.2	32.0
°F	66.2	59.5	120.7	104.4	89.6
Flashpoint					
°C	None	None	-7.0	-27.0	None
°F	None	None	19.0	-16.6	None
LFL/UFL (Vol% in Air)	None	None	1.5-8.7	3.6-13.3	7.6-17.7
GWP, 100yr [1]	< 5[2]	1030	< 25 [3]	794	725
VOC (US)	No	No	Yes	No	No
PEL [4]	800	300	600	1000	500

1. 2007 Technical Summary. Climate Change 2007: They Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (except where noted)
2. Private Communication, Prof. Don Wuebbles, University of Illinois, Department of Atmospheric Sciences
3. Generally accepted value
4. Manufacturers’ literature except where noted

LOW CLIMATE CHANGE IMPACT HOUSEHOLD REFRIGERATOR

Honeywell has reported in various papers and proceedings on the development of LGWP blowing agents in the various polyurethane PUR applications, including appliance foams. PUR foam properties of thermal conductivity (also known as lambda or k-factor), compressive strength, and dimensional stability derived from characterization of hand mix foams or foam panels prepared by means of a high pressure foam machine have evidenced efficacy in comparison to 245fa foams. This type of effort to develop baseline data is necessary to estimate the performance in the commercial manufacture of refrigerators, refrigerator/freezers, and freezers. However, until commercial refrigerator product has been manufactured under industrial conditions, and assessed for energy performance and ancillary performance, for example, liner compatibility, adhesion to liner and metal cabinet and doors, freeze stability, and other quality aspects, an OEM cannot make a prudent decision that a commercially viable, 'real world' solution is available.

Honeywell reported the performance of household refrigerators/freezers manufactured utilizing Solstice LBA, compared to baseline 245fa blowing agent in the same refrigerator platform. Further assessment has been performed utilizing a Solstice LBA appliance polyurethane system optimized for thermal conductivity, for which the resulting assessment will be discussed and contrasted to the prior reported data. To that end, a full scale trial, utilizing Honeywell Solstice LBA, with an optimized polyurethane system, in a commercially available 623 liter (22 ft^3) household refrigerator/freezer [bottom freezer, counter-depth platform] was undertaken. These 30 refrigerator cabinets, with associated door sets, were foamed to investigate:

- Lambda (k-factor) performance in various locations of the refrigerator
- Liner compatibility with High Impact Polystyrene (HIPS)
- Dimensional stability
- Freeze stability at target density
- Compressive strength
- Adhesion to plastic liner material and metal case
- Foam closed cell content
- DOE (Department of Energy) Energy Performance
    - Energy consumption with 134a refrigerant working fluid

The baseline comparison for these low climate change impact refrigerators is the same commercial household refrigerator/freezer product utilizing 245fa blowing agent and 134a refrigerant (unmodified compressor system). It should be noted that the Solstice LBA was substituted for 245fa at an equal molar level in the PUR foam formulation.

Polyurethane Foam Formulation

As discussed previously, the polyurethane formulation comprised commercially available materials, and was supplied by a major PUR systems house, with Solstice LBA equal molar substituted for 245fa. The foaming process conditions including machine temperatures and pressure were identical to the conditions for the 245fa baseline cabinets and doors. The polyurethane process parameters are illustrated in Table 2. Those familiar with refrigerator factories and scale will observe the scale of foam throughput is consistent to scale found in North American world-scale factories, and is consistent with the size refrigerators manufactured in this trial.

Solstice LBA processed very similarly to 245fa and no modifications were made to the PUR foaming equipment or process- effectively, conventional existing PUR equipment, existing in the factory, accommodated Solstice LBA.

Additionally, characterization of the Solstice LBA versus 245fa foamed cabinets and doors suggest no differences in minimum fill weight or over-pack conditions.

Table 2. Appliance PUR Formulation and Process Parameters – Typical

Component	245fa (% wt)	Solstice LBA (% wt.)
Polyol Blend	71.3	→
Additives	4.3	→
Water	1.0	1.0
Blowing Agent	23.4	24.0
Isocyanate	100	100
Door Foam Rate: kg/min (lbs/min)	40.8 (90)	40.8 (90)
Cabinet Foam Rate: kg/min (lbs/min)	90.7 (200)	90.7 (200)
B-Side Temperature °C (°F)	18.3 (65)	18.3 (65)
A-Side Temperature °C (°F)	23.9 (75)	23.9 (75)
Gel Time (sec)	30.0	30.0
Tack Free (sec)	45.0	45.0
Injection Pressure MPa (psi)	10.4 (1500)	10.4 (1500)

Lambda (k-factor) Performance

Foam samples from various locations in the fresh food compartment and freezer compartment were assessed for lambda (k-factor) performance. PUR foam thermal conductivity can and will vary throughout the refrigerator/freezer due to foam flow characteristics and associated density variation. Chart 1 illustrates the average lambda (k-factor) performance measured in varying locations of the refrigerator/freezer. Solstice LBA lambda performance is approximately 3% improvement to 245fa baseline. Across multiple Solstice LBA household refrigerator assessments, across the various regions, the lambda performance has exhibited improvement to 245fa baseline, as well as significant improvement to cyclopentane.

DOE Energy Assessment

The U.S. Department of Energy (DOE) established, in July 2001, a standard for the maximum energy consumption of household refrigerators. In simplified terms (Federal Register 10CFR 430 for more detail) the standard allows a maximum energy usage by refrigerator internal volume, adjusted for various accessories, such as through-the-door water and ice dispensers. In addition, the DOE provides for the Energy Star label for refrigerators, refrigerator/freezers, and freezers, which, as of March 2008 is DOE Standard minus 20% energy consumption. Presently the DOE is in the process of establishing, for promulgation in 2014, a revised and presumably more stringent energy standard for household refrigerators, refrigerator/freezers, and freezers.

Lambda (k-factor) assessments aside, meeting the DOE energy standard is the only criteria that determines whether a refrigerator meets the energy requirements to be sold in the U.S. The refrigerator/freezers manufactured in this trial not only met the DOE Standard, not only met the DOE Energy Star label, but exceeded the Energy Star label requirements. Five refrigerator/freezers utilizing Solstice LBA in an optimized PUR system / 134a refrigerant were assessed by the DOE Energy Star test method. Five refrigerators/freezers utilizing 245fa blowing agent in an optimized system / 134a refrigerant was the baseline comparison.

Effectively, the 2011 refrigerators, as well as the 2009 refrigerators, containing Solstice LBA in an optimized PUR system, exceeded the proposed DOE 2014 Energy Standard, without employment of further energy solutions to the platform, such as vacuum insulation panels or compressor modification.

Comparative Energy Consumption Performance

Resulting from comparative blowing agent assessment conducted by the Association of Home Appliance Manufacturers / Insulation Technical Advisory Committee (AHAM / ITAC) in the mid 1990s, it was recognized that refrigerators manufactured utilizing cyclopentane blowing agent exhibited approximately 8-10% energy efficiency penalty compared to those manufactured with 245fa. While PUR systems for both blowing agents have improved over the last decade, the relative energy efficiency gap has remained. While Solstice LBA has demonstrated improved energy efficiency to 245fa, the continual question surrounds the comparison to cyclopentane, and the relative energy efficiency thereof. For comparative blowing agent performance to have validity, requires build up and energy consumption assessment be performed on identical refrigerator platform. Additionally, accepting there are formulation nuances between fluorocarbon systems and hydrocarbon systems, the PUR formulations utilized were commercially utilized performance systems. Illustrated in Chart 2, with 245fa refrigerator energy consumption performance has the zero point on the y-axis, Solstice LBA consistently is 1.5-3.0% energy consumption reduction to the commercial 245fa baseline, and 8.0 – 10.0% improvement to cyclopentane (95%) baseline. Further noted is that multiple data points on differing refrigerator platform configuration and sizes were incorporated into this analysis.

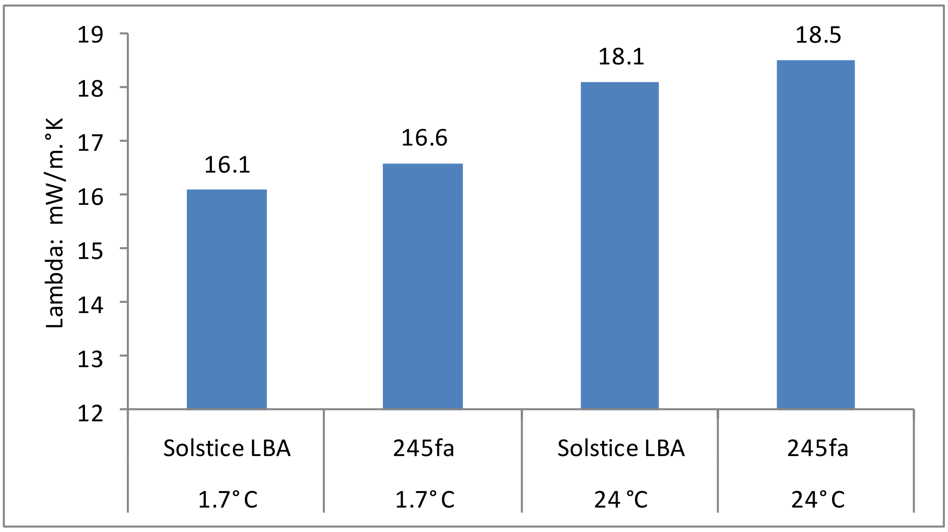

Chart 1. Average lambda measured across various refrigerator/freezer locations-Typical

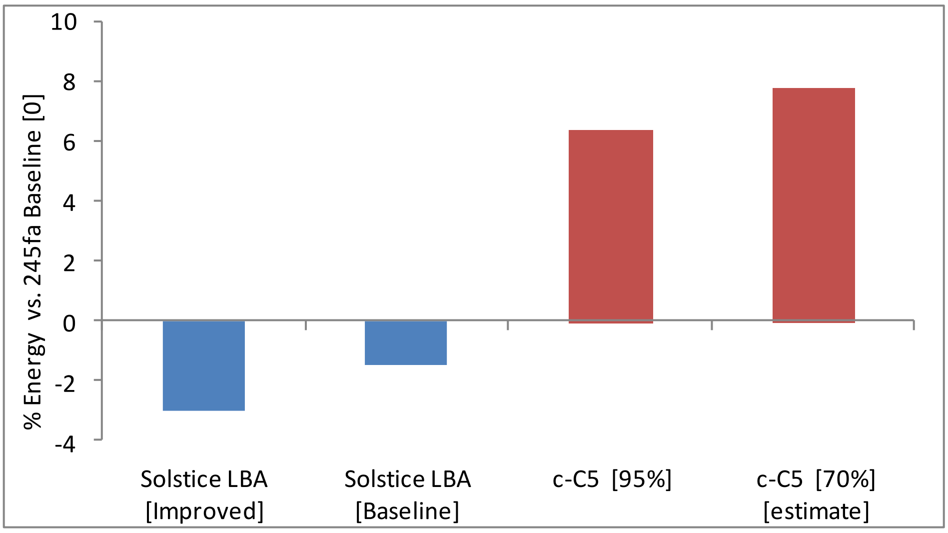

Chart 2. Comparative Energy Efficiency Performance.

Climate Change Impact

Climate change impact of a household refrigerator, over a typical 15 year lifetime, encompasses two discrete elements: direct and indirect. Direct climate change impact associates the impact of raw materials, which for this analysis includes impact of blowing agent manufacture, transportation, emissions in refrigerator manufacture, and end of life emissions [with the general assumption that blowing agent will be released to the atmosphere from the PUR insulation foam]. Indirect climate change impact relates to the lifetime energy use for the refrigerator. While modern HFC blowing agents, such as 245fa exhibit improved insulation performance over non-HFC blowing agents, such as hydrocarbons and others, various regulatory bodies have expressed concern over GWP property of these materials, particularly as relates to end of lifetime management and fugitive emissions from manufacturing processes, despite the energy efficiency imparted in PUR insulation by these blowing agents.

At EEDAL 2003 conference, 'The Effect of Blowing Agent on Energy Use and Climate Change Impact of a Refrigerators' [Johnson and Bowman], a comparative analysis for a Whirlpool 'Combi' 358 liter refrigerator was reported for which validated data was available. This analysis was constructed around the separate use of HFC-245fa and a hydrocarbon blend (cyclopentane) as blowing agent for the PUR insulation, and the resulting energy consumption performance. This analysis showed that the direct impact of either blowing agent was orders of magnitude less than the indirect impact (lifetime energy consumption of the refrigerator). LCA calculations for Solstice LBA have shown the carbon footprint to be of the same order of magnitude as 245fa and hydrocarbons. Hence indirect impact (lifetime energy use of the refrigerator) is the overriding factor, for minimizing climate change impact, and the choice of blowing agent for PUR insulation foam – the underlying assumption of GWP < 15 property of the blowing agents.

Chart 3 illustrates the comparison of PUR insulation containing Solstice LBA to PUR insulation containing a pentane blend utilizing the same analysis. The difference in CO_2 equivalent, exceeding 15% (including PUR ageing effects, op.cit.), represents the respective lifetime climate change impact of the blowing agent choice, all other refrigerator platform design elements equal. The caveat: within the construct of regulation (absolute energy consumption or labeling) the 15% energy consumption gap must be recovered by design elements, which may include: changes to insulation wall thickness, incorporating vacuum insulation panels, improvement in compressor efficiency or fan motor efficiency, as well as other solutions. Inclusion of these design elements, for recovering the energy consumption gap into finished refrigerator product represents a manufacturing cost to the OEM, as well as a societal cost to the consumer at retail.

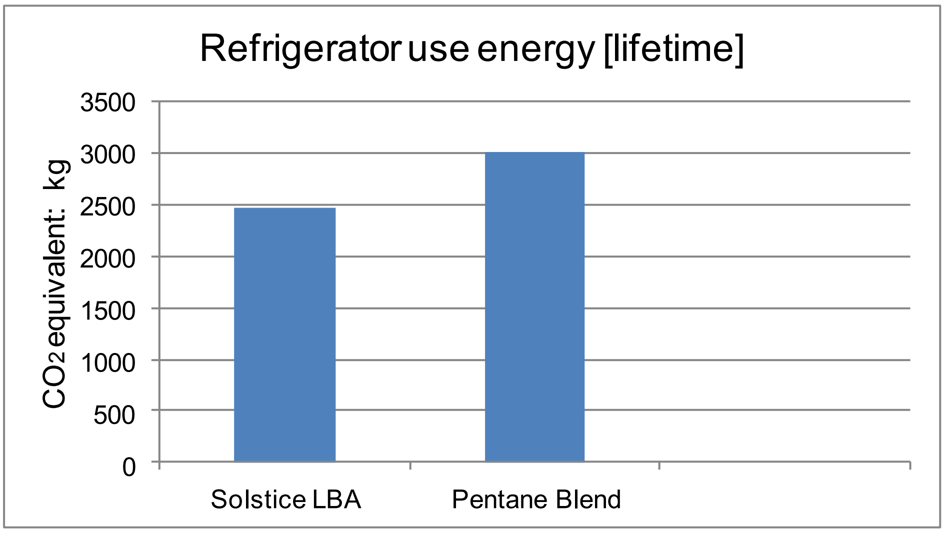

Chart 3: Energy Consumption: Refrigerator Lifetime

SUMMARY: Household Refrigerator Energy Performance

Commercially manufactured in 2009, 710 liter (25 ft^3) household refrigerator/freezers with Solstice LBA, equal molar substituted for 245fa, in a commercially available 245fa appliance PUR formulation, exceeded the DOE Energy Star performance criteria and exceeded the 245fa baseline performance.

Commercially manufactured in 2011, 623 liter (22 ft^3) household refrigerators, utilizing an optimized Solstice LBA PUR system exhibited an energy efficiency improvement to the baseline 245fa refrigerators exceeding 4%. Further, this 623 liter refrigerator/freezer platform exceeded the 'proposed' DOE 2014 Energy Standard for this platform.

Across multiple differing household refrigerator platforms, use of Solstice LBA blowing agent in the PUR insulation has exhibited 8 – 10% improvement (reduction in energy consumption) compared to use of cyclopentane (95%) as the blowing agent in the PUR insulation.

Within the scope of a limited life cycle climate performance analysis, the climate change impact of blowing agent choice is not insignificant, and may offer manufacturing cost improvements to the OEM.

Solstice LBA, in all ancillary assessments related to a household refrigerator/freezer, met or exceeded all requirements, including liner compatibility, compressive strength, dimensional stability, and freeze stability. At this writing, numerous scale household refrigerator assessments have been performed in not only U.S., but in various regions. Efficacy of Solstice LBA energy efficiency in refrigerator/freezers and related economic improvement in raw materials utilization is being demonstrated and acknowledged.

ENVIRONMENTAL and REGULATORY STATUS

The European Parliament and the Council of the European Union have committed the Community and its Member States to the adoption of the Kyoto Protocol in reducing anthropogenic emissions of greenhouse gases listed in Annex A to the Kyoto Protocol by 8% compared to 1990 levels in the period from 2008 to 2012.

The F-Gas Regulation as outlined in (EC) No 842/2006 (OJEC L161 of 14.06.2006) prohibits the use of fluorinated greenhouse gases in certain (emissive) applications. F-Gases include certain HFCs (hydrofluorocarbons), PFCs (perfluorocarbons), and SF6 (sulfur hexafluoride) as listed in Annex I (EC 842/2006). The EU F-Gas Regulation is under review, which may result in additional use restrictions for high GWP fluids (Article 10, F-Gas Regulation), as well as introduction of a 'cap and phase-down' mechanism.

Although current activity is limited, the United States government is considering various approaches to address climate change, particularly regulatory-driven changes. While still too early to predict the final structure and language, changes will impact high global warming potential materials to some degree. In anticipation of these regulations, and in response to similar regulatory initiatives globally, industry is preparing solutions to meet current and future climate change regulations. Honeywell counts among this group of industries with its low GWP development program, including, in addition to blowing agents, refrigerant gases and other fluorochemicals.

Japan has made voluntary Kyoto Protocol commitments to reduce or limit emissions of greenhouse gases, though has not formally promulgated domestic regulations to enforce these commitments. Solstice GBA and Solstice LBA can play an important role in meeting these voluntary commitments.

It is anticipated that, as climate change regulations are developed in other countries, these regulations will contain GWP limits similar to those being promulgated in Europe and, voluntarily, in Japan. Solstice GBA and Solstice LBA will, in all likelihood, satisfy the requirements of these regulations and will therefore be an integral part of any GWP reduction strategy, as well as ODS (ozone depleting substances) strategy for Article V countries. Indeed, Canada, Mexico and the USA have submitted proposals for a "Cap and Phase Down" mechanism under the Montreal Protocol that envisages a gradual reduction in the GWP-weighted consumption of certain fluorinated greenhouse gases (mainly HFCs) globally. If adopted, the effect of such a mechanism would be that low GWP fluids would become the preferred solution in many applications.

Low GWP materials, because of their very short atmospheric lifetime, often prove to be volatile organic compounds (VOCs), contributing to ground level ozone formation. The measure that characterizes whether a chemical is a VOC is the Maximum Incremental Reactivity (MIR). This measure (MIR) at which chemicals are generally considered to be a VOC, by U.S. regulation, is that of ethane. The MIR of Solstice LBA has been measured at less than the value for ethane, hence has been classified as VOC-exempt in the U.S. (Carter, W. P L., 2009). The European Union uses a somewhat different measure to characterize propensity for ground level ozone formation -- photochemical ozone creation potential (POCP) -- which is compared to ethane, which has a POCP of 12.3 (Nielsen, University of Copenhagen). The POCP of Solstice LBA [1233zd(E)] is less than ethane, and calculated POCP to be approximately 3. The short atmospheric lifetime of Solstice LBA also explains why, in spite of the presence of a chlorine atom in its structure has a negligible Ozone Depleting Potential [Wuebbles – University of Illinois (private communication): 1233zd(E) exhibits no impact on depletion of ozone layer and is commonly referred to as zero (0)]. Solstice LBA degradation products are well known compounds that are abundantly present in the natural environment.

Honeywell's Solstice LBA can provide insulation performance improvement, while additionally providing a substantial reduction in greenhouse gas emissions when used in place of high GWP products currently regulated under the F-Gas regulation. Since the purpose and intent of climate change regulations is to control emissions of high GWP materials, Solstice LBA, with a GWP of < 5, is in the same GWP range as many other blowing agents that are considered low GWP solutions, such as hydrocarbons and certain other blowing agents. Therefore, Solstice LBA provides a path to lessening the global warming potential issues facing the industry.

The Solstice family of blowing agents is unique in possessing four important environmental properties: no impact on the ozone layer; very low global warming potential; low photochemical ozone creation potential; and no flammability.

PRODUCT REGISTRATION STATUS

In the European Union, REACH [Registration, Evaluation, Authorization and Restriction of Chemicals, (EC) 1907/2006] regulation has, effective June 1, 2008, replaced the notification provisions of directive 67/548/EEC. Under REACH, each manufacturer or importer of a substance over 1 metric ton per year is obliged to submit a registration file, including a chemical safety assessment for volumes greater than 10 tons. For volumes over 100 and 1000 metric tons, additional data must be submitted. Moreover, for these volume bands, the registrant must submit proposals for animal tests needed to obtain certain (eco) toxicological data points. The goal of the latter provision is to prevent, as much as possible, duplication of animal tests. In many cases, waivers for such tests can be proposed. The registration should indicate the intended uses for which the substance is notified. Use outside these registered uses is prohibited, unless a downstream user submits a separate registration file for that use. REACH Registration of Solstice LBA is in progress, and presently at the 10 metric tons band.

In the United States, commercialization of new materials requires U. S. Environmental Protection Agency (EPA) compliance with Section 612 of the Clean Air Act (CAA). Toxicology data is submitted to the EPA, together with an application for a Premanufacturing Notification (PMN). Approval of the PMN includes the material's listing on the Toxic Substances Control Act (TSCA) inventory. Further, materials to be used as blowing agents or in certain other applications must have listing as an acceptable substitute for ozone-depleting substances under the Significant New Alternatives Program (SNAP). Completion of the PMN review process and listing on the TSCA inventory is a requirement for all new chemical materials. SNAP listing is a requirement for all materials in applications that have historically used chlorofluorocarbons (CFCs). Upon completion of these regulatory requirements, new materials can be commercialized in the United States. Additionally, these materials may be regulated at the federal, state, or local levels to comply with volatile organic compound (VOC) regulations. Solstice LBA filing for SNAP and PMN has been completed and is currently under U.S. EPA review, as is VOC exemption status.

For Japan, the requirements for commercialization of new chemicals requires submission of toxicological and environmental data to the Japanese Ministry of Health, Labor and Welfare (MHLW), the Ministry of Economy, Trade and Industry (METI), and the Ministry of the Environment (ME) for compliance with the Chemical Substances Control Law. Solstice GBA and Solstice LBA registration in Japan is complete.

Other regions of the world have requirements for toxicology assessment and environmental impact assessment prior to commercialization of new materials. Honeywell is committed to obtaining the necessary regulatory clearances for sampling and eventual sales of the Solstice family of blowing agents, and more specifically, Solstice LBA globally. This registration process is in progress for Solstice LBA in several countries, including China, South Korea, Australia, Canada, and others.

TOXICITY ASSESSMENT

At the writing of this paper, Honeywell has made significant progress towards completing all necessary toxicology studies and assessments for use and commercialization of Solstice LBA. Toxicology data has been submitted to regulators in connection with regulatory filings in the United States, specifically the SNAP, PMN, and the EU REACH programs, and has been independently reviewed by leading toxicology labs and third party reviewers.

CONCLUSIONS

Across multiple refrigerator assessments, incorporating various platform configuration and size, Solstice LBA blowing agent (PUR insulation) has exhibited improvement to energy efficiency contrasted to 245fa baseline, and significant improvement to cyclopentane baseline.

Solstice LBA regulatory approvals are in place or in process in major markets, encompassing excellent properties of ultra low GWP (GWP < 5), no flammability, and low POCP (classified as non-VOC by U.S. EPA).

With the global attention to climate change, and potential restrictions on the use of high GWP blowing agents and refrigerant gases in various regions of the world, Honeywell and Whirlpool have validated the energy efficiency of Solstice LBA low GWP blowing agent in the context of North American design household refrigerator platforms.

ACKNOWLEDGEMENTS

Honeywell acknowledges the significant contributions by the Whirlpool Corporation and other multinational appliance OEMs for their collaboration in providing the manufacturing site and refrigerators, as well as the multinational polyurethane systems companies in providing the polyurethane formulations utilizing Solstice LBA.

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Tim is currently Director Regulatory Affairs, Compliance and QA with Honeywell Fluorine Products Europe, Middle East & Africa and adviser to Honeywell's UOP Renewable Energy & Chemicals business. He holds leading positions in Industry Bodies such as the European Fluorocarbon Technical Committee (EFCTC), EPEE (European Partnership for Energy and the Environment) and CEFIC. He also chairs the Fluorocarbon REACH Consortium Coordination Group.

Mr. Vink was a lead author for the IPCC/TEAP Special Report on the relationship between the Montreal Protocol and Kyoto Protocol as it affects Fluorocarbons. He is (co-) author of several articles related to chemicals. In addition, Mr. Vink has been actively involved in the development and application of a wide body of EU legislation, including REACH, the European Climate Change Programme, Waste- and Energy Efficiency rules, Renewable Energy and Fuel Quality, as well as Trade related issues. A Dutch citizen, Mr. Vink received a Masters Degree in Economics from the University of Nancy II (France) with honours. He is also a graduate from the Centre Européen Universitaire de Nancy (France) and the Nijenrode School of Business (NL).

Unveiling the mysteries of refrigerator energy consumption

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Abstract

We all know what a refrigerator looks like. Most households in developed countries have one (or more) at home and many households in the developed world have one already or will have one soon.

It is well known in general terms that household refrigeration uses a lot of energy. Refrigerators and freezers are regulated for energy consumption in as many as 60 countries. While generalised modelling approaches allow us to make reasonable guesses about their energy consumption at a national or global level, the reality is that we do not really know much about the drivers of energy consumption when it comes to individual appliances (such as number of householders and climate).

The problem is that the way we measure the energy consumption of a refrigerator in the laboratory (for energy labelling and Minimum Energy Performance Standards) is really nothing like the way they are normally used. In fact, we don't really have much of an idea of how they are normally used. We don't know what temperatures are inside people's houses, we don't really know how different refrigerators respond to changes in ambient temperature. We don't know how much energy is associated with usage such as door openings and cooling food and drinks and how this impacts on appliance energy.

As part of his PhD research, high quality energy data (as well as indoor temperature data) has been collected from some 300 refrigerators and freezers installed in real homes (over a period of 6 months to 1 year). This is the most comprehensive study of its type anywhere in the world. The data set collected to date is formidable and provides deep insights. To complement field data, the research also utilises extensive laboratory data for hundreds of models.

The paper explores the key findings of these important field and laboratory measurements and what they mean for our understanding of energy for these appliances. Importantly it provides insights into what to measure to facilitate more accurate energy consumption estimates during normal use and how the new IEC test method sets out these key components. The paper also outlines new government proposals to increase MEPS levels in 2017 and to change the whole approach to energy labelling of these products into Australia to make it more accurate and consumer relevant.

Introduction

Most developed countries have large numbers of household refrigerators installed and operating. Australia, which is by no means exceptional, currently has an ownership of household refrigerators of about 1.4 per household. Separate freezers account for a further 0.4 appliances per household [1]. Australia has almost 9 million households, so this accounts for about 16.2 million appliances operating in 2013 (for a population of almost 23 million in March 2013). In addition it is estimated that there are a further 1.5 million appliances operating in offices and workplaces that are effectively used for household purposes, bringing the total close to 18 million appliances. These appliances account for some 12% of residential electricity consumption in Australia [2]. By any measure this is a significant end use.

Globally, some 100 million new refrigerating appliances are produced every year. There are nearly 1.5 billion products installed world wide [3]. These products are estimated to consume some 1,000 TWh of electricity a year, equivalent to around 5% of global electricity consumption [4].

It is therefore somewhat surprising how little is known and published about refrigerator energy consumption during normal use and the key drivers for this energy consumption. While there have been many end use metering campaigns over the years to measure energy of household refrigerators in the field, this data has provided little insight and understanding on the key elements that can affect efficiency. This paper sets out some of the early finding of a major research project undertaken by the author as part of his PhD at the University of Melbourne which aims to provide a much deeper view into the conditions of use and how this impacts on energy. While the research is still in progress, this paper sets out many of the key drivers that have been gleaned from years of experience and research in the field. Hopefully this will provide useful background to policy makers in all countries on how to deal with this ubiquitous product in a more coherent manner.

Technical Basis of Operation

Before delving to a deep technical analysis of laboratory and field data, it is useful to recap what a refrigerator actually is and how it works. This discussion is limited to products that use the vapour compression cycle as overwhelmingly these dominate systems that are connected to electricity grids around the world.

In its simplest manifestation, a refrigerator is an insulated box to which is attached a heat pump. The heat pump consists of a compressor, a condenser, an expansion control system (typically capillary tubes for household style refrigerators) and an evaporator, all connected in a loop and filled with an appropriate charge of refrigerant. The heat pump collects energy from inside the refrigerator and pushes it to the outside using the vapour compression cycle (or Carnot refrigeration cycle).

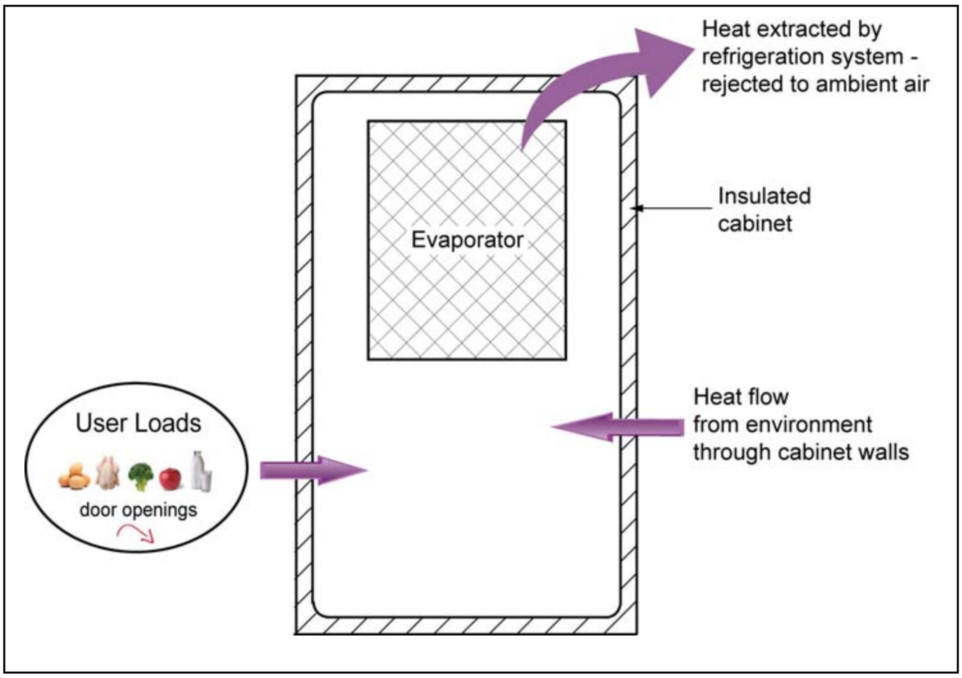

Figure 1: Schematic representation of a simple refrigerator

Typically, the refrigerants most commonly used are R134a and R600a (iso-butane). The most common insulation used is polyurethane as this is one of the best performing insulation materials available (blowing agents for the foam do vary). There are some other components in the system (such an accumulator to stop liquid exiting the condenser from reaching the compressor in liquid form, and some more exotic designs like multiple evaporators and complex expansion systems), but these all work within the same broad principles. Other common options are inverter driven (variable output) compressors, which offer advantages in many operating conditions, options for automatic defrosting, a range of auxiliaries like through the door dispensers, automatic ice making and so forth. Heaters are also commonly used for a range of purposes such as temperature balance, external humidity control and keeping water lines to freezers in a liquid state, as well as for maintaining stable operation in some ambient conditions.

In simplistic terms, the energy consumption of a refrigerator under any operating condition (excluding user interaction) is determined by 2 main factors:

- The effective overall average insulation of the cabinet walls – this determines the heat flow from the surrounding ambient air into the refrigerator cabinet;

- The efficiency of the refrigeration system to remove that heat gained in order to maintain constant internal temperatures.

For a simple, single compartment refrigerator or freezer, the measured steady state energy consumption is given by the following equation:

$$P = \frac{U \times A \times (T_a - T_i)}{COP}$$

Where:

U is the overall average U value of cabinet walls

A is the surface are of the cabinet walls

T_a is the average ambient temperature around the refrigerator

T_i is the internal average temperature of the refrigerator

COP is the efficiency of the refrigeration system.

Increasing insulation decreases the heat load while increasing the COP of the system reduces the energy required to extract the heat load. There are of course many small elements that can impact on the overall effective U value of the cabinet such as penetrations, variable thickness, use of composite materials like vacuum panels in some areas and heat gain through door seals (gaskets). Once a refrigerator is designed, the insulation, surface area and to some extent internal operating temperature are fixed (once a control setting is selected by the user).

The following elements that impact on energy are explored in some detail below:

- Impact of ambient temperature on energy
- Typical indoor temperatures
- User loads
- Defrosting
- Compartment temperature controls

Impact of Ambient Temperature

Change in ambient temperature is an obvious element that a refrigerator has to deal with in normal use. The first important effect is that an increase in ambient temperature results in a linear increase in heat load through the compartment walls (irrespective of the number of compartments present and their operating temperature, as many straight lines add to give a composite heat gain as a straight line). The only way to reduce this heat load is increased insulation (lower U value) or a smaller surface area (there is limited scope to alter this parameter for a given compartment size). An increase in ambient temperature decreases the operating efficiency (COP) of the compressor. Clearly user interactions add additional heat to be extracted in the top row of the above equation. In many situations that can comprise a substantial heat load on the product. User related heat loads also increase with ambient temperature (as a result of hotter temperatures and also heavier use).

The second important effect is that an increase in ambient temperature increases the condenser temperature for the refrigeration cycle, thus reducing the overall operating efficiency of the system. While academic literature notes that changes in condensing temperature normally result in a fairly linear change in compressor COP (at least for reciprocating compressors, which are widely used in household refrigerators) this is not widely known or understood (not that the idealized Carnot efficiency is not linear with changes in condensing temperature). To examine this issue in more detail, published data from a wide range of compressor manufacturers has been examined.

When designing a product, refrigeration engineers focus on the worst likely operating condition for the product – typically this is an ambient temperature of 40°C or warmer. This is the condition where the heat load into the cabinet is extremely high and the condensing temperature is very high so the compressor is operating at minimum capacity and efficiency. The two main compressor rating systems are ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) and CECOMAF (Comite Europeen des Constructeurs de Materiel Frigorifique = European Committee of Manufacturers of Refrigeration Equipment – see EN12900). Both rate compressors at these extreme conditions[1] as this is what designers need to know to correctly size them for their products.

During product operation the evaporator remains within a relatively small temperature range – this is dictated by the operating temperature of the compartment (typically the evaporator would be 7K to 10K colder than the coldest compartment temperature it is cooling), so around -21°C to -25°C for a typical freezer (the issue of user selected temperature change is discussed later). So the effect of most importance during normal use is the change in condenser temperature (as we can assume that the evaporator stays within its normal hysteresis limits). The following figure shows data compiled from published on line catalogues for Embraco in Brazil.

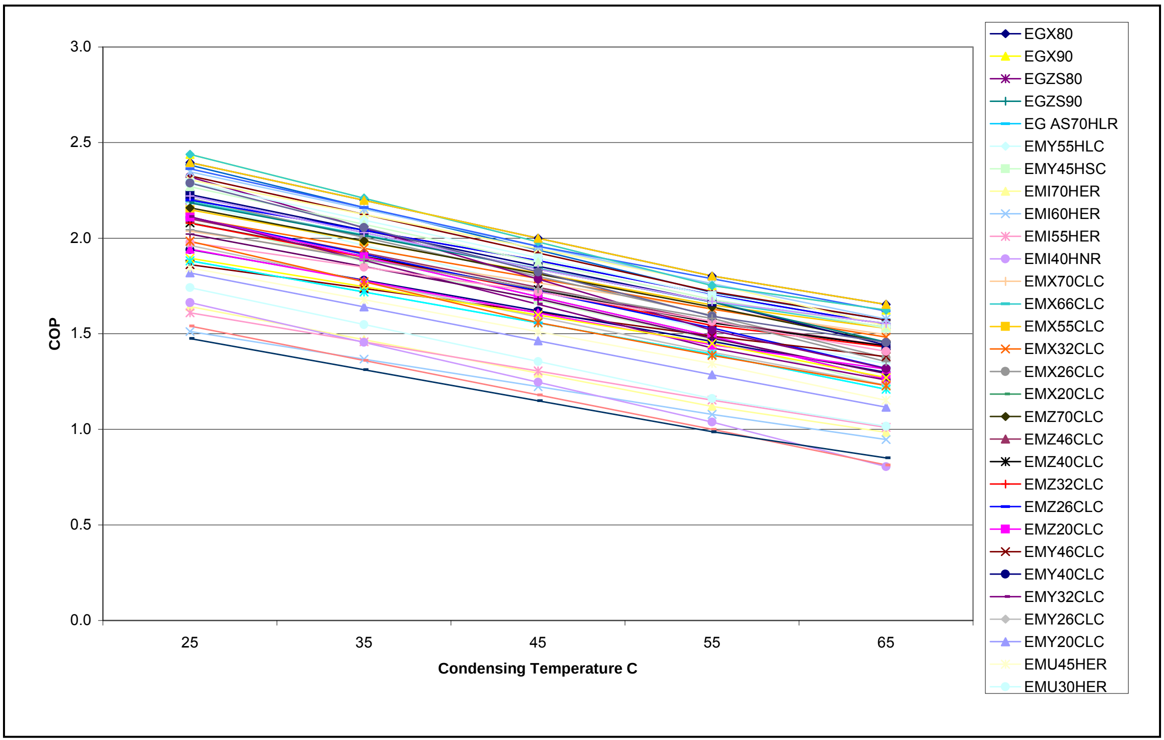

Figure 2: Condensing temperature versus compressor COP - ASHRAE

Source: Author analysis and compilation of data from www.embraco.com – note that published rating figure is for a condensing temperature of +54.5°C.

The data in this figure suggests that the slope of COP per K change in condensing temperature is linear (as expected) and almost constant for different sizes and different COP ratings for different compressors. The remarkable point here is that all compressors, irrespective of their rated COP, appear to exhibit roughly the same slope in response to changes in condensing temperature. The reason for this is being investigated, but one theory is that once the compressor overcomes it operating inefficiencies (such as clearance volumetric efficiency, which largely dictates its overall operating efficiency) then the compressor responds to changes in operating conditions somewhat like an ideal gas compressor (hence similar slope).

[1] CECOMAF conditions are a condenser and liquid temperature +55°C and an evaporator temperature of -25°C. ASHRAE conditions are condenser temperature +54.4°C, liquid temperature of +32°C and an evaporator temperature of -23.3°C.

Deeper analysis shows that there is no obvious difference between R600a and R134a compressors. There is a difference between ASHRAE (COP slope on average of about 0.018 per K) and CECOMAF (COP slope on average of about 0.03 per K - the difference being the assumed sub-cooling in the ASHRAE rating system). In effect this means that we can expect all compressors to respond to changes in condensing temperature with the same COP change per K, which effectively means that the slopes of all compressor maps are roughly parallel with changes in condensing temperature. This is a useful fact that can help understand the changes in appliance energy with changes in ambient temperature.

An increase in ambient temperature results in a linear increase in heat load and a linear decrease in the operating COP. The result is a non linear increase in steady state power in response to an increase in ambient temperature (this can be approximately represented as a quadratic equation).

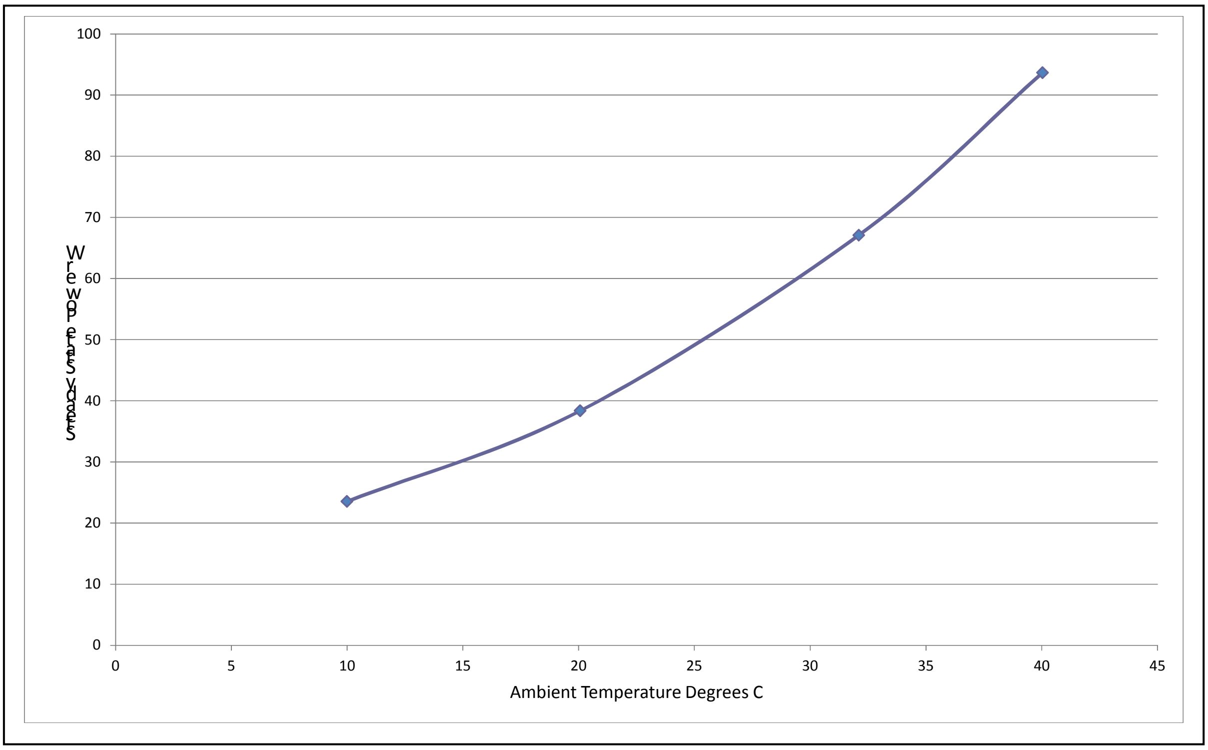

Figure 3: Typical change in steady state power with change in ambient temperature

Over a fairly typical range of operating temperatures (from 15°C to 30°C), the expected underlying power could be expected to double. A smooth curve, such as shown in Figure 3, occurs where the internal temperatures are steady across ambient temperatures and there are no heaters used. Heaters, which are commonly used at low temperatures for internal temperature balance, can make this type of curve appear to kink significantly.

Typical Indoor Temperatures

Having established that ambient temperature has a strong impact on energy, it is useful then to examine the like range of indoor temperatures that an appliance may experience. This gets into an area that appears to be highly variable across countries and regions and is driven by a range of factors such as climate, building shell performance, use of space conditioning equipment and user habits and practices.

In Australia, there have been extensive indoor measurements by the author, which provide some insights indoor the range and distribution of indoor temperatures. Culturally, most householders do not operate space cooling in summer except on hotter days (at least in the major cities – in the far north air conditioner use is more prevalent). Indoor temperatures tend, on average, to reflect ambient temperatures and they tend to be slightly warmer than outdoor temperatures, on average. The main user related influence, when examining capital city data in in Figure 4, is that some heating is used in Sydney in winter and quite a bit of heating is used in Melbourne in winter (divergence between outdoor and indoor temperatures). Most households tend not to heat to a constant temperature all day in winter (even in Melbourne). This means that average indoor temperatures are cooler than would normally be considered comfortable. In contrast, countries like Sweden tend to have constant indoor temperatures in winter of around 20°C even though outdoor temperatures are very cold [5], while southern European countries tend to have cooler indoor temperatures in winter.

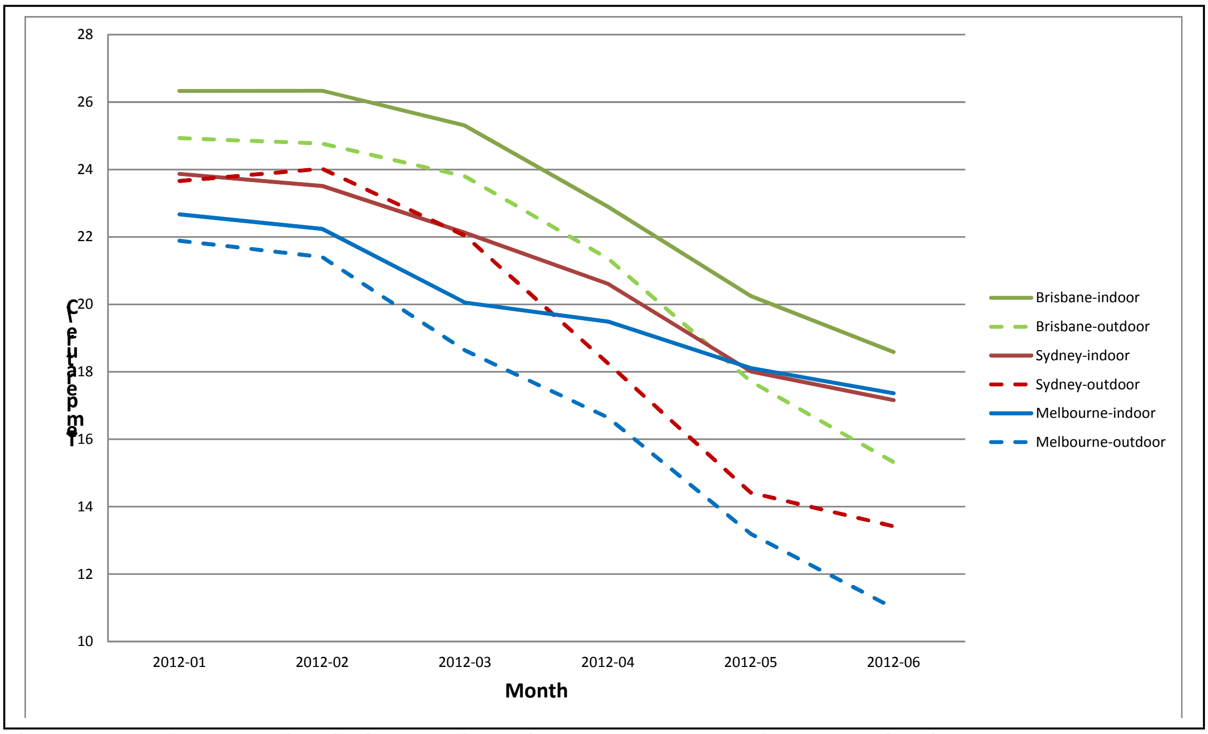

Figure 4: Typical monthly indoor and outdoor temperatures in Australian homes

Sources: Author field measurements and Australian Bureau of Meteorology

It is important to note that the indoor temperatures by city are for living areas which are typically conditioned spaces – i.e. where the householder identifies that there is a heater or cooler and that this is used in winter and/or summer. In Australia about 30% of all household refrigerating appliances are in unconditioned spaces or effectively outdoors, and are therefore exposed to more extreme temperature ranges. Deeper analysis of the data suggests that for outdoor temperatures the daily standard deviation is around 3K to 4K[2], while for indoor temperatures, the standard deviation is more typically 1K to 3K (less for an efficient building shell and/or where space conditioning equipment is used more consistently. Use of space conditioning is clearly influenced by climate and culture. In Australia, New Zealand and Japan, indoor temperatures in some households can be as cold as 5°C [6] and [7] at some times of the day in winter.

User Loads and Energy

There is currently a poor understanding of user related loads and even less documentation on their energy impact. Conceptually, user store food and drink in their appliances for later use. Temperatures need to be controlled to preserve foodstuffs or to ensure that it is at a temperature suitable for serving. To access the stored food, users have to open the door(s) to place items in the refrigerator or to remove items. So user related loads can be broken down into the following elements:

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[2] In practical terms, this is a typical max-min temperature difference on a daily basis of around 7K.

- Cold air inside the appliance being displaced by warmer ambient air during a door opening which then has to be cooled (sensible heat load)
- Humidity in the ambient air being transferred by air exchange (latent heat load)
- Cooling of food or drink items placed in the appliance (sensible heat load)
- Humidity load from food or drink items (especially respiration by fruit and vegetables and evaporation from uncovered liquids) (latent heat load)
- Radiant heat gain when the door is open (generally considered to be negligible).

The latent loads above also contribute to frost build up on the evaporator. Where remote evaporators with fan forced air circulation are used (now very common in higher end refrigerator-freezers) humidity loads also may decrease defrosting intervals (although this is a second order effect in terms of energy impact, unless the defrost interval is very short). All of these user loads increase the heat load on the inside of the refrigerator that has to be removed by the refrigeration system – this is on top of the normal heat gain through the cabinet walls.

To gain an understanding of how much impact user interactions have on energy consumption of refrigerators, it is necessary to examine field measurements of energy consumption of refrigerators during normal use. But field measurements of energy are highly variable and potentially very confusing unless there is a rigorous framework for analysis and disaggregation of the data. The author has developed a methodology to allow such disaggregation of field energy data into its component elements. The principle of the approach is that the steady state power consumption of an appliance should be constant where there is no user interaction and no defrost activity. Therefore, examination of the actual energy consumption of the appliance at any point in time can provide a means of quantifying the energy associated with user interaction, as long as the ambient temperature at the time is known and an ambient response curve for the appliance can be determined.

If the appliance is measured for long enough, there will eventually be a large number of points where there is no user interaction spread across a wide range of ambient temperatures. These will effectively define an ambient response curve for the appliance, like the one shown in Figure 3. For this approach to be successful, it is necessary to measure the energy for at least 6 months with coverage for both summer and winter, as indoor temperature and user loads are both strongly seasonal. The other requirement for this approach is that the energy data has to be collected in a way that allows individual compressor cycles to be identified and separately analysed. Compressor cycles are the fundamental building block of energy consumption for a refrigerator, so all energy measurements are normally examined in terms of these control cycles. While this technique has long been applied to the analysis of laboratory test data, it is not applied, as a general rule, to field data. In part this is because this requires data to be collected at equal intervals of 3 minutes or less so that the start of each compressor cycle can be accurately identified. Extensive experience has shown that 10 min data, which has been commonly used for field measurements of appliances, cannot be applied in that manner.

This approach allows user loads to be calculated by deduction. It is also possible to identify each defrost event and the energy associated with them. The no usage "edge" to the data in Figure 5 is effectively an equivalent curve to that shown in Figure 3.

Over the past decades, as well as recently, there has been a lot of focus on door openings and their impact. Part of the research being undertaken by the author is examining door openings and their influence as a component of user loads. Generally, it is extremely difficult to obtain reliable door opening data in the field, as this normally requires the fitting of special data logging equipment. The published literature reveals few studies that quantify measured door openings in the field: a UK study in early 1990's (60 appliances, 39 door openings per day) and one in Germany in 2007 (34 appliances, 24.7 door openings per day) (both cited in [8]). Some field work has been undertaken in Japan where some 52 appliances (in 26 homes) were measured, each over a 2 week period. The data logging equipment to measure door openings was able to provide a distribution of the length of time for each opening (averaging about 10 seconds across all door types, but with a range from 2 sec to 50 sec). The number of door openings was recorded as 36/day for the fresh food compartment, 7.4/day for vegetable, 7.4/day for freezer and 1.3/day for ice making. Most of these products had 3 to

5 separate doors. Total door openings were 51/day for all doors. This is somewhat higher that the other two field studies that recorded door openings (as reported above), but differences may be due to cultural differences and product configurations. Door openings seem to be an area that is systematically underestimated by users when they are asked to self report.

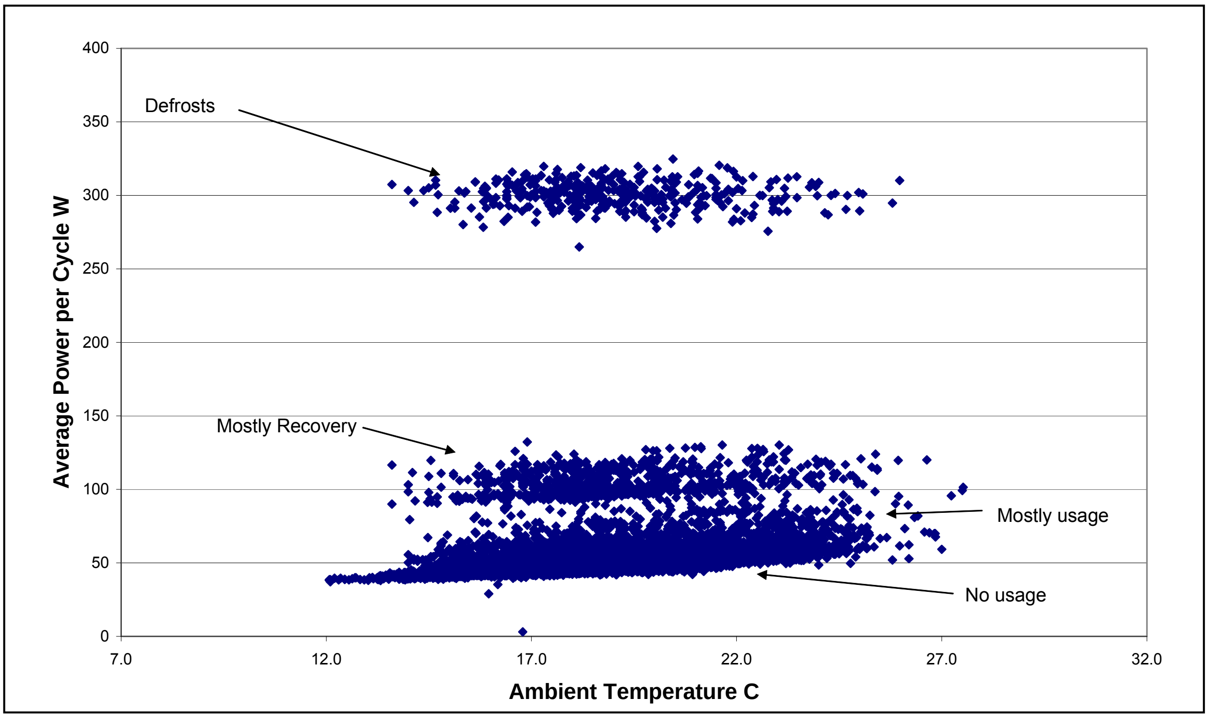

Figure 5: Individual compressor cycle data for over 1 year

As part of the field research undertaken in Australia, door opening data has been provided via access to data collected by the refrigerators themselves. The range of Active Smart refrigeration appliances made by Fisher & Paykel in New Zealand have an on board computer that collects a wide range of operational data as part of its ongoing control strategy. Some of this data is available for download via a special tool for service personnel[3]. One aspect of great interest is a listing of door openings for the past 10 defrost cycles and for newer models, a count of door openings by compartment over the life of the appliance. A routine analysis of these downloads by Fisher & Paykel in 2008 allowed information to be established in door openings for about 50 refrigerators spread across Australia, New Zealand and the USA, each with data recorded for about 280 days (total period covered 13,000 days).

This data was reported at the IEC SC59M meeting in Munich in November 2008 [9]. The mean number of openings for fresh food were 30.5 per day and for freezers 4.5 per day and the average was similar in all 3 countries covered. Clearly these values will be affected by factors such as demographics and whether the appliance is primary or secondary, and these factors have not been controlled in this data collection process. Preliminary analysis of 80 on-board downloads from 45 Australian refrigerators puts the average fresh food door openings at 42 per day (ranging from 11 to 94 per day averaged over 1 week) and freezers at 4.7 per day. Clearly these are influenced by demographics, so the author is looking to develop a model of door openings by householders.

A range of laboratory test data has been examined on the impact of door openings. Most laboratory tests report this impact as a percentage of the test room steady state power consumption (typical values are reported in the range 3% to 10%, depending on the frequency and duration of door openings tested). However, laboratory results are of limited value for two reasons. Firstly, the number of door openings tested is usually significantly less than the actual number of door openings (based

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[3] Fisher & Paykel have been very generous with their support of field research on refrigerators through the provision of software and tools to collect this type of data and their support is gratefully acknowledged.

on field measurements). A related issue is that ambient humidity in refrigerator test rooms is usually quite low, so the latent component can be significantly underestimated. The second reason why these sorts of tests and calculations are of limited value is that they manifest as an energy consumption impact on the appliance itself – they do not directly estimate the heat load that the appliance has to remove. To understand this, we need to estimate the operating COP of the refrigeration system. For example, two refrigerators may have the same general internal layout but may have very different operating COPs. One with a high COP will only show a small energy impact from user loads while one with a low COP will show a much larger energy impact from user loads under the same operating conditions.

It is possible to calculate the heat load equivalent of a door opening using psychrometric data. An example of this was given in Annex L of an early Committee Draft of the global IEC standard (IEC 59M/24/NP – see www.iec.ch). The example given in that document is of a 300 litre fresh food compartment and a 100 litre freezer: this would have a total heat load equivalent of 4.4 Wh per opening for the fresh food and 2.63 Wh per opening for the freezer (assuming a complete air exchange and an ambient temperature of 32°C with 40% relative humidity). At an ambient temperature of 16°C and a relative humidity of 70%, these values are 2.52 Wh and 1.86 Wh respectively. In reality, door openings are mostly short[4], so there is only limited air exchange (probably around 50% of these values). But given that in summer humidity may be more than 40% (the energy load is quite sensitive to humidity) and the number of door openings can be quite high, the expected heat load from door openings alone in summer would be on average of the order of 150 Wh/day[5]. On top of this is the sensible heat load of food and drinks (a single 2 litre bottle of drink cooled 28K is equivalent to a heat load of 65 Wh), which can be very significant. There can also be radiant heat impacts if the door is left open for a significant time.

Field measurements for some 200 refrigerators have been completed and another 100 appliances are currently being measured. Analysis of the data is still in progress, but preliminary data suggests that typical summer usage impacts are around 300 Wh/day or more while in winter these may be around 150 Wh/day. These estimates clearly are impacted by factors such as the number of householders (more users generate more interactions) and the presence of second or third appliances (the most significant impact being that a separate freezer appears to reduce user interactions on freezer compartments of refrigerator-freezers). Work is being undertaken to develop a demographic model of user related loads. Initial investigations suggest operating COP of refrigerators varies in the range 0.7 to 1.3 under warmer test conditions (32°C ambient). Interestingly, this is often significantly lower than the rated COP of typical compressors used even taking into account the likely temperature rise across the evaporator and condenser. This is an area where more intensive research is being undertaken. One area of fruitful research is measurement of practical field operating COP values through the use of small heaters[6]. This provides a quick and relatively simple way of quantifying performance in the field with minimal equipment.

User Selected Temperature Settings

This is an area that has traditionally received a lot of attention in test methods. However, based on responses to user questionnaires, the majority of users never or only rarely adjust their temperature settings. The results of a research questionnaire conducted by the author of household participating in field measurements are summarized below:

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[4] Japanese data showed that average door openings were around 10 sec and Fisher & Paykel data indicates that 99% of door openings are less than 30 sec in duration.

[5] It is important to consider these heat loads in context. A typical refrigerator-freezer at an ambient test temperature of 32°C will use from 40W to 80W steady state, so 300 Wh could represent as much as 35% of total energy in the normal use. Field measurements suggest that user impacts can be as high as 50% of total energy in some cases, but 20% to 25% is more typical. This depends on the household and the refrigerator characteristics as the COP affects the impact of user loads.

[6] Horticultural heating mats made of rubber with an embedded element with a rated power of about 20W have been found to be very useful. It is important to measure energy input in the heat as well as the change in the refrigerator power consumption. This is best done overnight when there is little user interaction. Products with limited temperature balance capability have been found to have a poorer apparent operating COP as the temperature in the non-heated compartment often drops even though additional cooling is not required – but this to some extent is a reflection of actual use as user loads are never proportionally added to both compartments at the same time.

Fresh food compartment temperature control changes (count 171 appliances):

- Never 61%
- Once or twice a year 34%
- 2 monthly or more often 5%

Freezer compartment temperature control changes (count 154) of refrigerator-freezers:

- Never 77%
- Once or twice a year 21%
- 2 monthly or more often 2%

For separate freezers, 93% never adjust the temperature controls (in fact many people do not realize that there is a temperature control for the separate freezer or the freezer compartment). This is a significant finding for a number of reasons. Firstly, there is some anecdotal evidence that those appliances where the users reported "regular" changes to compartment temperatures tended to be older ones, ones that are not working very well and those with poorer temperature control (e.g. where lettuce freezes etc.). The second point is that changes in fresh food temperatures tend to have small overall impact on energy consumption. Detailed analysis of test report data for many hundreds of appliances concluded that the energy impact per degree K temperature change for fresh food compartments was 1% to 2% while the energy impact per degree K temperature change for freezer compartments was 3% to 4% (for refrigerator-freezers) [10]. For separate freezers and all refrigerators the impact is around 5% per K. But the reality is that these controls are rarely changed in practice.

If an appliance is working properly, the user will have little need or inclination to change the control settings. Of course it is important when undertaking comparative laboratory tests to control the compartment temperatures to obtain fair and accurate results.

Defrosting Energy

While direct cooling (manual defrost) products are still common in developing countries, frost free products (with a remote evaporator and forced air) now predominate refrigerator-freezers in developed regions such as Japan, North America and Australasia. Due to the advanced analytical techniques developed for the forthcoming global IEC test method for refrigerators, a deep understanding of defrost energy characteristics has been obtained in recent years.

Consider the data in Figure 6. The product is in a lab in a steady state condition – both power and compartment temperatures are stable with compressor cycles of around 50 minutes. A defrost occurs from period 17, made up of:

a) A short compressor cycle at the start (truncated) at 139W for 20 minutes (cycle 17)

b) Immediate operation of the defrost heater at 165W for 19 minutes (average 135W over 24 minute cycle) (cycle 18)

c) Recovery cycle at about 95W for about 1 hour 20 minutes (cycle 19)

Note that these "cycles" are control events and are not of equal length as noted above. For this appliance there is a change in freezer temperature during the defrost (small kink in the freezer trace), but this is quite small. From an analysis perspective, the area under the defrost and recovery "hat" (as shown in Figure 6) is the incremental energy associated with a defrost and recovery event. In this particular case the incremental energy is about 95 Wh (integrating power difference with time across cycles 17 to 21). This is a fairly typical value for defrost and recovery – most products are in the range 70Wh to 130Wh in the test laboratory, based on the analysis of many hundreds of products. To put this into perspective, in this particular case, the steady state power is about 65W, which equates to 1560 Wh per 24 hours. If the defrost were to occur once per day (fairly typical), the incremental defrost energy of 95 Wh would account for a 6% increase in energy above steady state. If the defrost were to occur every 12 hours (quite short) the defrost energy would account for a 12% increase in energy above steady state. If the defrost were to occur once every 36 hours (also possible for intelligent products), then the incremental defrost energy would account for a 4% increase in energy above steady state. Consideration of the incremental defrost energy in isolation is of little value – the typical defrost interval in each condition also needs to be estimated. This also shows that modest changes in defrost intervals do not have large impacts on total energy consumption, except where these are very short in normal use.

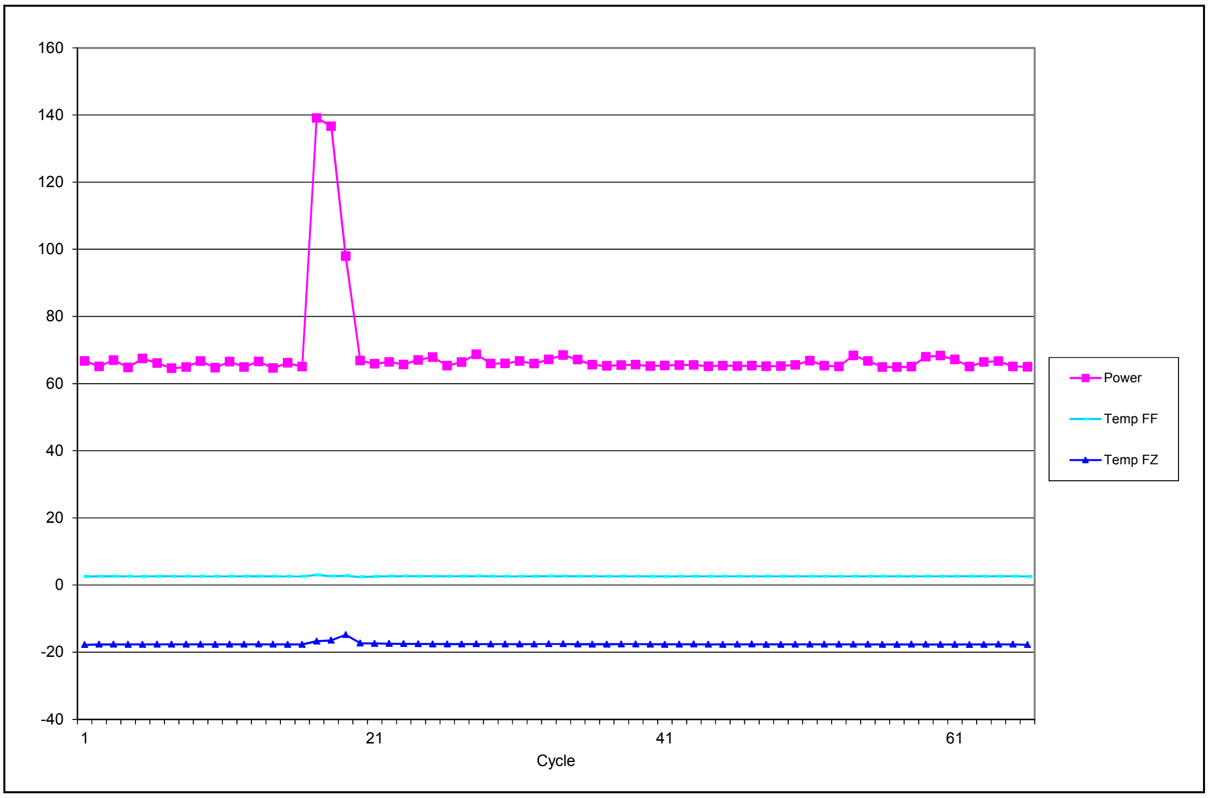

Figure 6: Average power (W) and temperature data (°C) by compressor cycle, with defrost

The thing that is most interesting and non-intuitive about incremental defrost energy is that this value changes little with changes in temperature control setting or even with ambient temperature. The reason for this is based on solid physics of the event. The process of defrosting involves stopping the compressor, melting ice from the evaporator and then restarting the compressor to "recover" back to the conditions before the defrost (for sample calculations see [11]). It is possible to calculate the energy required for this process: the main components are melting ice, warming the metal in the evaporator and any refrigerant inside, cooling the evaporator (and refrigerant) down again. While it is true that some product designs are not very good and appear to allow some heat from the defrosting process to enter the compartment during this process, this effect is generally small and the new IEC test procedure now penalizes designs where the compartment temperature rises during defrost (and reward products that have a pre-cool before defrost to avoid temperature rises) as the temperature through the defrost is counted in the overall compartment temperature[7]. The compartment often warms a little during defrost just because the cooling system has stopped. The energy impact of an enforced stop of refrigeration is very small (if anything, this reduces energy slightly by allowing compartment temperatures to warm a little). So it is the melting of ice and warming and cooling the evaporator that is important in terms of defrost energy (not the temperature setting or the ambient conditions). A larger evaporator will have a larger incremental defrost energy, but it will also have a larger surface area (greater operating efficiency) and most likely a longer period between defrosts.

[7] Note that the new US Department of Energy test procedure for refrigerators, which is largely aligned with the new IEC, does not measure temperature change during defrost and recovery, so suppliers in North America may have less incentive to minimise temperature transients during defrost and recovery.

In a test laboratory, the frost load on the evaporator is generally low as there are no scheduled door openings and no food loads. Even still, some ambient humidity will always find its way into the compartment as the air inside the compartments expands and contracts with each compressor cycle (often called "breathing"). But the defrosting load in the lab is much lower than in normal use. Most products with electronic variable defrost controllers will vary the defrost interval through a learning process during normal use to keep the defrost heater on-time between optimum limits (typically between 15 and 20 minutes). These types of products assess refrigeration load, door openings and defrost heater on times for each defrost and revise the defrosting interval based on a fuzzy login algorithm. In the lab with a low humidity loading, these types of systems can have defrost intervals of 60 to 100 hours (which can create issues for test labs).

In normal use the frosting load on the evaporator will be much higher than in the lab. Typically a product in the lab with an incremental defrost and recovery energy of 100Wh will have a value in the field of the order of 150Wh in the field, mostly of the difference due to the increased frost load. This is one area where the test method needs to be adjusted to take into account normal use. It is important to examine defrosting intervals in the field versus the test laboratory – this is an area where some manufacturers have employed so called circumvention tactics to reduce the apparent energy in the test laboratory when compared to field use.

Other Factors

There are a range of other factors that can impact on energy consumption of refrigerators. These include auxiliaries (e.g. ice makers and water dispensers), humidity control devices (e.g. electric ambient controlled anti condensation heaters) and other small heaters and fans to provide stable temperatures. Mostly these are uncommon, are of small consequence to energy and/or are directly measured and accounted for in test procedures.

One important issue that has received little attention in the academic world is the impact of compressor starts and stops on overall refrigeration efficiency. When the compressor stops, refrigerant flows around system until pressures equalize, much of this ending up in the "wrong places" when the compressor next starts. When the compressor starts, any liquid refrigerant in the evaporator must be stored in an accumulator, to stop liquid entering the compressor (liquid refrigerant will normally damage the compressor). So typically the system is starved of refrigerant for some minutes until the refrigeration cycle is fully re-established again. Initial investigations suggest that around 2 minutes of compressor running is effectively lost at each compressor start (the output is zero at the start and this gradually builds up to full output over 7 to 10 minutes, but the overall effect is a few minutes of ineffective compressor operation). This is relatively minor at a hotter ambient temperature with long compressor run times, but in lower ambient temperatures, compressor run times can be as short as 8 minutes, meaning that 25% or more of total running is starting losses. A useful examination of the issues is given in [12].

New Global IEC Test Procedure for Household Refrigerators

As reported at previous conferences, IEC SC59M has been working on a new global test method for household refrigerators for the past 6 years. In May 2013, this was released as a Committee Draft for Voting and it is hoped that the standard will be published in early to mid 2014. This approach to energy and performance testing has been developed using state of the art measurement and analysis techniques and importantly, it has a global perspective in mind during its development. The key points that make this a truly global test method are:

- Options for ambient test temperatures at 16°C and 32°C, providing a sound basis to estimate regionally relevant energy values for a wide range of climates and operating conditions
- Separate characterization of defrost and recovery events
- Calculation of defrost intervals using a range of techniques allowing defrost behaviour to be tailored to local regions without the need to retest, and including their energy impact by calculation
- Measurement of load processing efficiency, to allow regional impacts of user interactions to be more accurately estimated

- Standardised compartment temperatures for energy tests
- A suite of uniform tests that aim to meet the testing and measurement needs of all regions.

One of the most exciting developments is that the US Department of Energy released a new test procedure in 2011 (finalized in 2012) that largely aligns with the requirements of the new IEC test method (IEC62552 Edition 2) (see [13]). This brightens prospects for a global alignment of testing approaches for what has traditionally been a difficult product in terms of harmonization. Australia has announced that it will align with the new IEC test method ([14]) and Japan is also likely to align shortly after publication. It is also being considered in a number of Asia countries.

Importantly, the test method will allow estimates of energy that are closer to actual use to encourage suppliers to optimize performance and energy consumption in that condition (suppliers currently only have an incentive to optimize energy for the test method, which is often far from normal use). Australia is proposing to adjust its approach to energy labeling based on the use of energy data at two ambient temperatures and processing load in order to move closer to that objective. While this is an important change,.a bigger energy impact is expected from the new Minimum Energy Performance Standards (MEPS) announced for introduction in 2017. These MEPS levels broadly align with the efficiency standards announced for introduction in the USA in 2014. More technical detail is available in [15].

Conclusion

Energy consumption of household refrigerators has been an area that has long suffered from poor test procedures and little understanding of how the products are used in households. Not only are existing test procedures poor in their design and application, there are many different variations in force in different regions, creating a mine field for manufacturers that operate in the global market.

Because of their significant energy consumption, refrigerators have been widely regulated for energy efficiency around the world. And there is little doubt that these regulatory programs have reduced energy consumption considerably over the long term. The next objective is to target energy programs so they encourage manufacturers to design their products so they minimize energy during normal use, not just at some artificial test condition. An important component of this will be rewarding products that have good load processing efficiency, as this makes up a substantial check of normal energy use.

Despite the strong regulatory interest in the energy consumption of these products for over 30 years (Canada and the US put mandatory energy labels on these products in 1978 and 1980 respectively, with Australia close behind in 1986) the overall understanding of what drives their energy consumption and what are the key components of their design and operation during normal use has been poor. The author is part way through an ambitious research project to measure energy consumption of nearly 300 refrigeration products in households over a long period to better understand the conditions in which they are used and the impact that users have upon their energy consumption. While much has been revealed in this paper on the inner workings of refrigerators, there is still much more to be done to conclude this important area of work.

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Dynamic Model for Predicting Energy Consumption of a Household Refrigerator

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Abstract

A dynamic model for predicting power consumption of household refrigerators is complicated because such a model must include not only refrigerator cycle components, but also refrigerator system software, variations in ambient temperature and occupants' usage behavior such as frequency and duration of door openings. We are developing a dynamic model for predicting power consumption of a household refrigerator that includes a refrigerator model, a compartment model, an occupants' behavior model, and a building simulation model. We are also using an actual refrigerator to obtain data for testing our models.

Evaluation of our model suggests that although some problems were present in predicting the working state of the compressor, the predicted value for total power consumption over twelve hours was close to that experimental value. The model application results show that the model can successfully simulate changes in working modes and increases in compressor runtimes in response to door openings. Results from the simulations suggest that annual power consumption can increase when operating the refrigerator in an air-conditioned room.

Introduction

As smart appliances, on-site power generation and demand response continue to expand, more importance is being attached to dynamic methods for simulating energy consumption by residential appliances. Household refrigerators play an important role in these expanding technologies because they contribute significantly to residential electricity consumption and their working mode can be controlled by external signals.

Much work has been done on developing the numerical simulation models for individual refrigerator components, including compressor, heat exchanger, capillary tube, cabinet, refrigerant loop, and control system. Recently, Hermes et al. [1, 2] proposed a transient model for household refrigerators that combines models for individual components. Later, Hermes et al. [3] and Borges et al. [4] simplified the model to predict energy consumption. However, predicting power consumption of a household refrigerator is more complicated than merely combing models of components; a reliable model must also account for variations in room temperature, occupants' usage behavior such as door openings.

Our research group is developing a dynamic model for predicting power consumption of a household refrigerator that includes a refrigerator model, a compartment model, an occupants' behavior model, and a building simulation model (see Figure 1). The purposes of this paper are to 1) understand physical and mechanical characteristics of a household refrigerator through laboratory experiments, 2) develop a simulation model for predicting the power consumption of the refrigerator, and 3) evaluate the power consumption of the refrigerator, considering occupants' behavior and variations in ambient temperature.

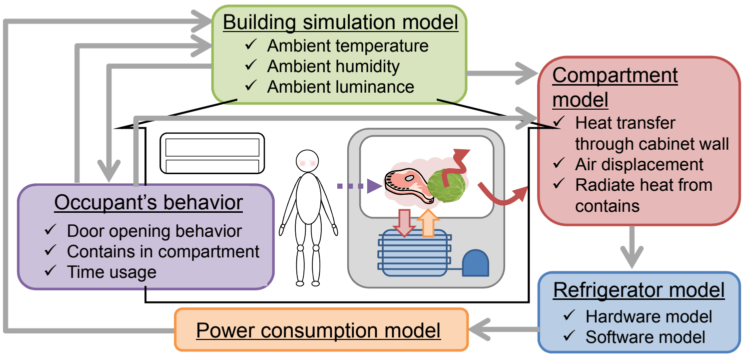

Figure 1: Schematic of the simulation model for household refrigerators

Experimental Method

The studied refrigerator and its basic features are shows in Figure 2. To understand the physical and mechanical characteristics of the refrigerator, experimental tests were carried out in an artificial climate chamber.

Release year	2011
Refrigerant	R600a
Refrigerant charge	80 g
Rated capacity of compartment	501 L
Rated power consumption of compressor	105 W
Rated power consumption of heater	197 W
Annual power consumption	220 kWh/year

Figure 2: Photo and basic features of the studied refrigerator

In order to determine model parameters, the experimental tests were conducted under the stable condition of the ambient temperature (5, 15, 20, 25, 30, 35, 40 °C) and the ambient humidity (50 %). In order to correct data for model validation, the ambient temperatures were represented by a sine function over time. The surface temperature of the refrigerant tube, the compressor speed and the power consumption were measured at intervals of 5 seconds (see Figure 3). The condenser heat transfer rate, the evaporator cooling capacity, and the isentropic compression work were calculated from experimental data on the basis of the theoretical refrigerating cycle.

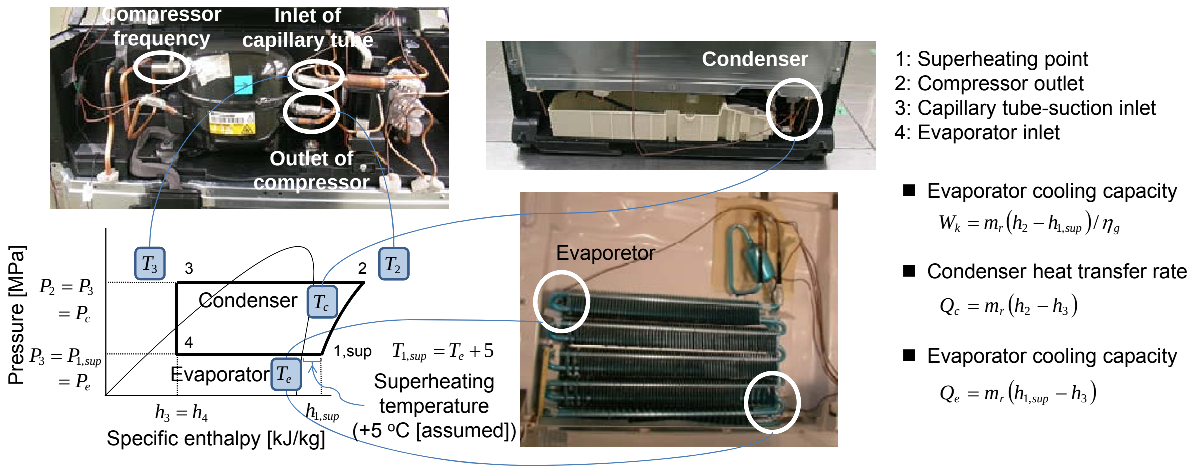

Figure 3: Points on the refrigeration cycle at which measurements were taken

Mathematical Modeling

The simulation model consists of the compartment sub-model, the software sub-model, the refrigeration loop sub-model and the power consumption calculation sub-mode (see Figure 4). The compartment sub-model calculates the mean compartment temperature on the basis of the ambient temperature and the time schedule of refrigerator door openings. The software sub-model determines the working mode (refrigerating and freezing, freezing only, defrosting, or standby) and the compressor speed on the basis of the ambient temperature and the compartment temperature. The refrigeration loop sub-model uses REFPROP ver.9 [5] to calculate the condenser heat transfer rate, the evaporator cooling capacity, and the isentropic compression work on the basis of the refrigerant temperature. The power consumption calculation sub-model provides the power consumption by using a linear equation that relate the power consumption to the isentropic compression work. Details of the sub-models are described below.

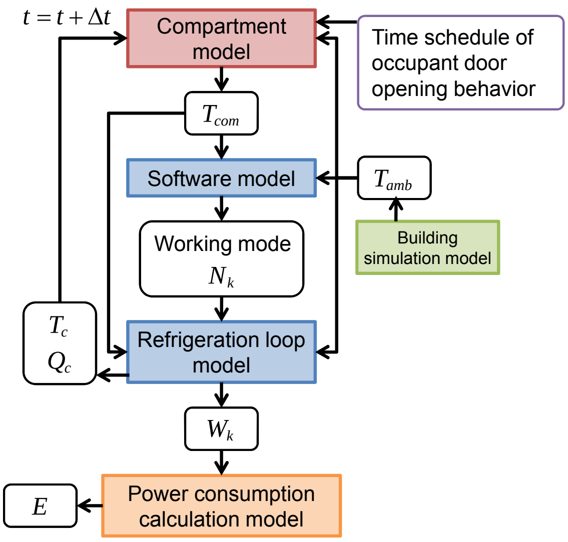

Figure 4: Flowchart of the simulation model

Refrigeration loop sub-model (steady-state)

The refrigeration loop sub-model provides the isentropic compressor work, W_k , the evaporator cooling capacity, Q_e , and the condenser heat transfer rate , Q_c , which are represented by the following equations.

$$W_k = m_r\left(h_2 - h_{1,sup}\right)/\eta_g \tag{1}$$

$$Q_e = m_r\left(h_{1,sup} - h_3\right) \tag{2}$$

$$Q_c = m_r\left(h_2 - h_3\right) \tag{3}$$

where h_1 is the refrigerant enthalpy at the compressor outlet, h_2 is the refrigerant enthalpy at the compressor inlet, h_3 is the refrigerant enthalpy at the capillary tube-suction inlet, and η_g is the overall compressor efficiency (= 1.0, assuming to be the isentropic process). The refrigerant flow rate, m_r , is obtained from:

$$m_r = \eta_v V_k N_k / v_1 \tag{4}$$

where η_v is the compressor volumetric efficiency (= 0.7), V_k is the compressor swept volume rate (= 10.17×10^{-6}), N is the compressor speed, and v_1 is the specific volume of the refrigerant.

The refrigerant temperatures at the compressor outlet, compressor inlet, and capillary tube-suction inlet were calculated from the following regression equations obtained from experimental tests.

$$T_*(t_*) = T_{*,s} - c_{1,*}\left(T_{*,s} - T_*(0)\right)\exp\left(-c_{2,*}t_*\right) \quad (5)$$

where $T_{*,s}$ is the refrigerant temperature at steady state, $T_*(0)$ is the refrigerant temperature at which a particular refrigerating mode starts ($t_r = 0$, $t_f = 0$), t_* is the elapsed time after a particular refrigerating mode starts, while $c_{1,*}$ and $c_{2,*}$ are regression coefficients. $T_{*,s}$, $T_*(0)$, $c_{1,*}$, and $c_{2,*}$ are given in Table 1 and Table 2 for each working mode.

Table 1: Terms in Eq. (5) for refrigerating and freezing mode

Parameter	$T_*(0)$	$T_{*,s}$	$c_{1,*}$	$c_{2,*}$
T_1	$0.98\ T_{amb} + 6.34$	$1.10\ T_{amb} + 6.91$	1.0	0.00411
T_2	$1.23\ T_{amb} + 17.81$	$1.16\ T_{amb} + 29.58$	1.0	0.00169
T_3	$0.90\ T_{amb} + 3.77$	$0.98\ T_{amb} + 4.66$	1.0	0.00052
T_c	$0.86\ T_{amb} + 1.76$	$0.90\ T_{amb} + 8.91$	1.0	0.00439
T_e	-28.26	-24.18	1.0	0.01076

Table 2: Terms in Eq. (5) for freezing mode

Parameter	$T_*(0)$	$T_{*,s}$	$c_{1,*}$	$c_{2,*}$
T_1	$1.10\ T_{amb} + 6.91$	-	1.0	0.0
T_2	$1.16\ T_{amb} + 29.58$	-	1.0	0.0
T_3	$0.98\ T_{amb} + 4.66$	-	1.0	0.0
T_c	$0.90\ T_{amb} + 8.91$	-	1.0	0.0
T_e	$T_e(t_{r,end})$	-27.52	-1.0	0.00388

The refrigerant superheating at the evaporator outlet was calculated from the following equation, where ΔT_{sup} represents the degree of superheating (assumed to be 5.0):

$$T_{1,sup}(t) = T_1(t) + \Delta T_{sup} \quad (6)$$

The condensing and evaporating pressures were given by:

$$P_c = P_{sat}\left(T_c\right) \quad (7)$$

$$P_e = P_{sat}\left(T_e\right) \quad (8)$$

The condensing and evaporate temperatures, T_c, T_e, were calculated from Eq. (5) by using the parameters given in Table 1 and Table 2.

Refrigerated compartment sub-model

The compartment air temperature can be described by the heat balance equation.

$$C_{com}\frac{dT_{com}}{dt}=UA_i(T_c-T_{com})+C_p\rho_a V_a(T_{amb}-T_{com})+Q_H+Q_c \quad (9)$$

where C_{com} is the thermal capacity of compartment inner air, and T_{com} is the mean temperature of all the compartments.

The first term of the right-hand side of the Eq. (9) represents the heat transfer through the cabinet wall. The cabinet wall was modeled with two thermal resistances and two thermal capacities (see Figure 5), because when the compressor is running, the inner temperature of cabinet walls is generally higher than the ambient temperature. C_* and UA_* were obtained from experimental tests as summarized in Table 3.

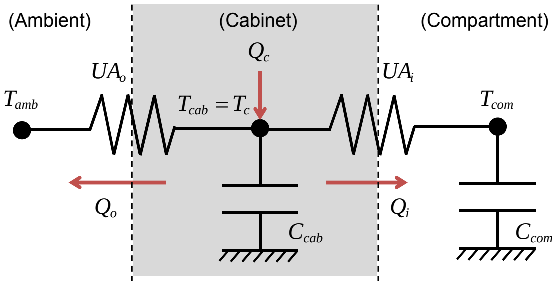

Figure 5: Schematic of the model used for cabinet walls

Table 3: Terms of Eq. (9)

Parameter	Value	
C_{cab}	30925.72	J/K
C_{com}	6046.76	J/K
UA_o	1.65	W/K
UA_i	8.55	W/K
αA	0.0545	m^2

The second term of the right-hand side of the Eq. (9) represents the heat transfer through air displacement caused by opening the refrigerator door. The displaced air flow rate, V_a, was calculated from:

$$V_a=\alpha A\sqrt{\frac{2}{\rho_a}\Delta p} \quad (10)$$

$$\Delta p=|\rho_{com}-\rho_{amb}|gh_c \quad (11)$$

$$\rho_*=\frac{353.23}{T_*+273.15} \quad (12)$$

where αA is the equivalent opening area, Δp is the pressure difference, h_c is the height from the floor to the center of the opening, and ρ_* is the air density. The equivalent opening area which represents the configuration resistance of the opening was obtained by using tracer gas decay method with CO_2 (see Table 3).

The third term of the right-hand side of the Eq. (9) represents the heat emission inside the refrigerator including radiation from foods, which was neglected in this study.

Software sub-model

The software sub-model provides the refrigerator working mode by following the flowchart in Figure 6. The refrigerator working mode is roughly divided into 4 modes: refrigerating and freezing, freezing only, defrosting, and standby. The temperature at which the refrigerating and freezing mode starts, $T_{on,r}$, is given by:

$$T_{on,r} = 0.05 * T_{amb} - 5.10 \qquad (13)$$

$T_{on,f}$ is the temperature at which the freezing mode starts (= -5.01). T_{off} is the temperature at which the standby mode starts (= -5.28). Δt_{def} is the interval time of defrosting (= 50839).

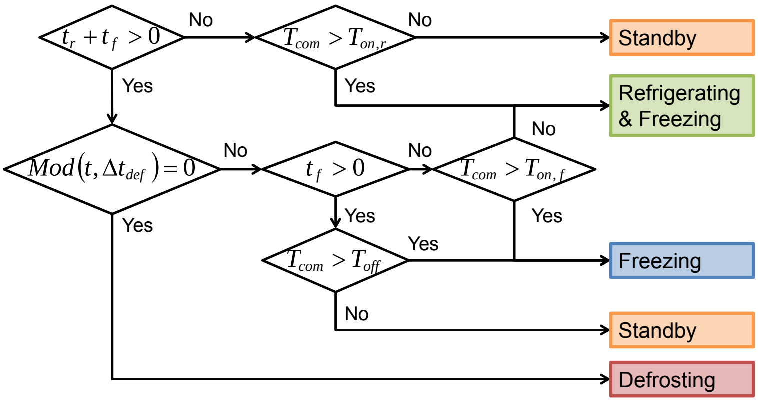

Figure 6: Flowchart for determining the refrigerator working mode

During the refrigerating and freezing mode or freezing mode, the compressor speed was determined from the procedure in Figure 7. At the first step, the compressor speed, $N_{k,1}$, is determined by the temperature difference between the set point for the temperature of the compartment and the ambient temperature (see Table 4). Either when the temperature difference between the set point and the actual compartment temperature falls below 14.5 °C, or when 3600 seconds have passed after the compressor starts working, the compressor speed moves to the second step. After the third step, the compressor speed changes every 600 sec.

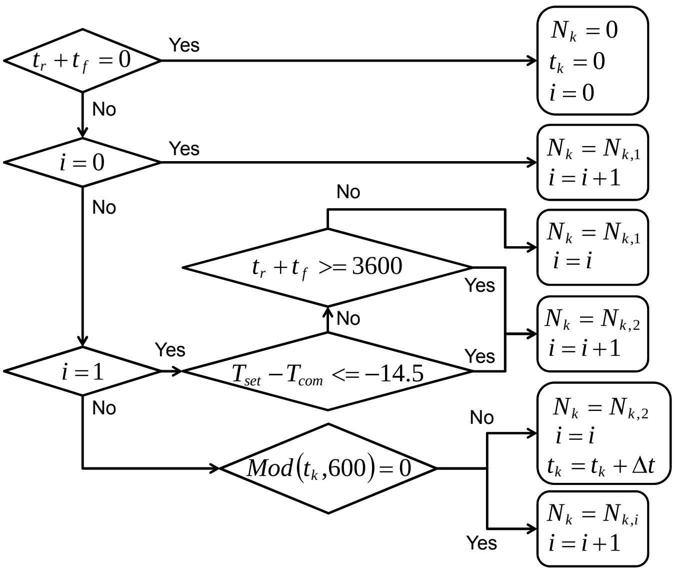

Figure 7: Procedure for determining the compressor speed

Table 4: Steps of the compressor speed

$N_{k,i}$	$T_{amb} - T_{com}$		
	< 25	25 - 35	35 <
$i = 1$	30	35	42
$i = 2$	35	42	52
$i = 3$	42	52	62
$i = 4$	52	62	62
$i > 4$	62	62	62

The defrosting mode includes pre-cooling, heater working, and post-cooling. The duration of each state is obtained from the following equations.

$$\Delta t_{*} = c_{3,*} T_{amb} + c_{4,*} \tag{14}$$

The terms of Eq. (14) are given in Table 5.

Table 5: Terms of Eq. (14)

Parameter	$T_{amb} < 30$		$T_{amb} >= 30$	
	$c_{3,*}$	$c_{4,*}$	$c_{3,*}$	$c_{4,*}$
Δt_{pre}	0	1839	62	-21
Δt_{heater}	0	2071	118	-1469
Δt_{post}	0	4803	1465	-39147

Power consumption calculation sub-model

In the refrigerating and freezing mode, and the freezing mode, measurements of power consumption, E, and isentropic compression work, W_k, gave the data shown in Figure 8. A liner fit to that data gives:

$$E = 1.22 W_k + 26.21 \tag{15}$$

which is the line in Figure 8. The intercept of that line represents the power consumption of accessories.

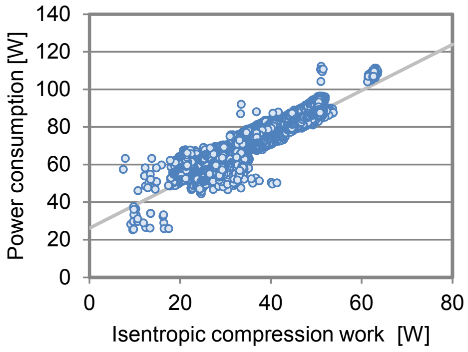

Figure 8: Relation between power consumption and isentropic compression work

In the defrosting mode, the power consumption was calculated from the duration and the mean power consumption of each state by the following equations.

$$E_* = c_{5,*}T_{amb} + c_{6,*} \tag{16}$$

The terms of Eq. (16) are given in Table 6.

Table 6: Terms of Eq. (16)

Parameter	$T_{amb} < 20$		$T_{amb} >= 20$	
	$c_{5,*}$	$c_{6,*}$	$c_{5,*}$	$c_{6,*}$
E_{pre}	0.00	70.58	3.96	-10.10
E_{heater}	0.00	192.92	0.00	192.92
E_{post}	0.00	70.58	2.89	12.78

Model Evaluation

Time-series data for the power consumption predicted by the model are compared with experimental results in Figure 9. The model did not predict the working state very well. For example, the duration of a compressor on-off cycle predicted by the model was smaller than that observed in the experiment. Consequently, the number of on-off cycles predicted by the model was larger than observed in the experiment. One of the reasons for this was that the model underestimated the compressor runtime especially at average ambient temperatures above 23 °C, as described in Figure 10. The power consumption during the compressor runtime was slightly overestimated, as shown in Figure 11. Over the twelve hours observed in the experiment, the total power consumption was 728.3 Wh, while that predicted by the model was 721.7 Wh. The error was 6.6% (0.9 Wh).

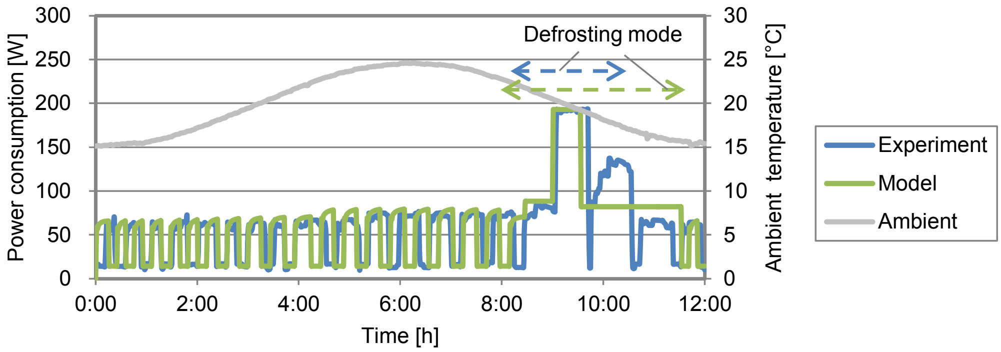

Figure 9: Comparison of calculated and measured power consumption over 12 hours

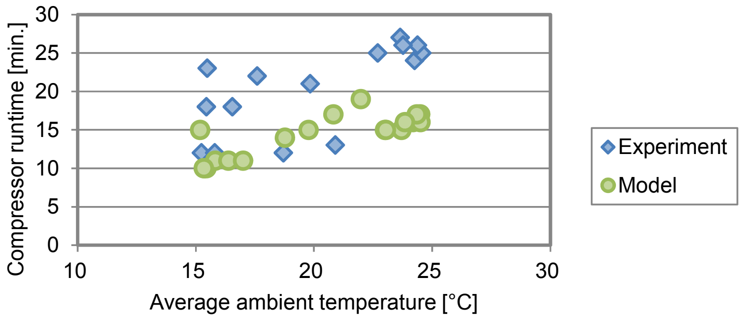

Figure 10: Comparison of compressor runtime

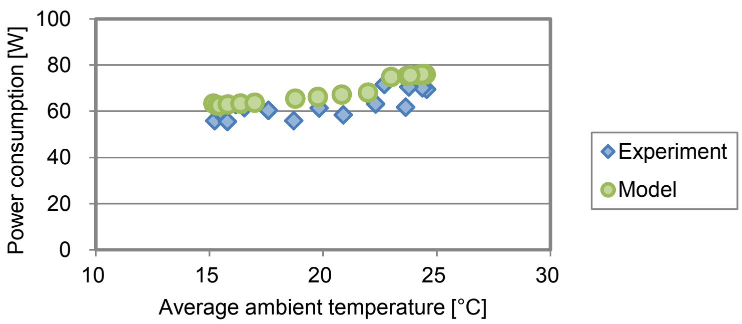

Figure 11: Comparison of average power consumption

Model Application Results

Simulation setup

In the simulation, the refrigerator was placed in a detached house with average thermal insulation. The user was the member of a four-person family: a male office worker, a housewife, a female high school student, and a male junior high school student.

Every 5 minutes, occupants' activities and the state of air conditioning were randomly provided to the simulation by the sub-models of the residential energy end-use model [6]. The refrigerator door was assumed to be opened during cooking, eating, and clearing up after meals. The durations of door openings were taken to be given as Table 7. The daily average cumulative duration of door openings was 320 s/day, which is close to the value provided by the Japanese Industrial Standard (350 s/day) [7]. Door openings occurred intensively during breakfast and dinner (see Figure 12).

Table 7: Assumed durations of door openings during occupant activities

Activity	At the beginning of the activity	During the activity
Having meals	10 sec.	-
Cooking	20 sec.	5 sec. every 5 min.
Clearing the table	10 sec.	5 sec. every 5 min.

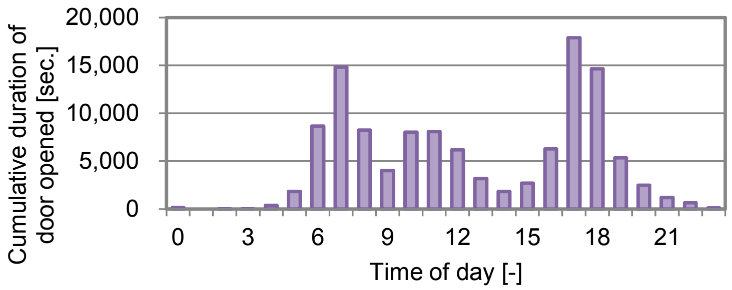

Figure 12: Hourly cumulative durations of door openings over one year

The ambient temperatures were calculated by the thermal network model at 5-min intervals, using the weather data for Osaka city, Japan. The power consumption of the refrigerator was calculated at 1-min intervals by giving a time schedule for door openings and ambient temperatures to the developed refrigerator model. In order to discuss the effects of door openings and ambient temperatures on the power consumption of the refrigerator, the three cases were set up. In Case 1, door openings followed the daily schedule described above, but no air conditioning was done to ambient air. In Case 2, neither door openings nor air conditioning occurred. In Case 3, both door openings and air conditioning occurred.

Results and discussion

Daily variations in the predicted power consumption of the refrigerator are presented in Figure 13 for Case 1. The model was successful in simulating changes in working modes and increases in compressor runtimes in response to refrigerator door openings.

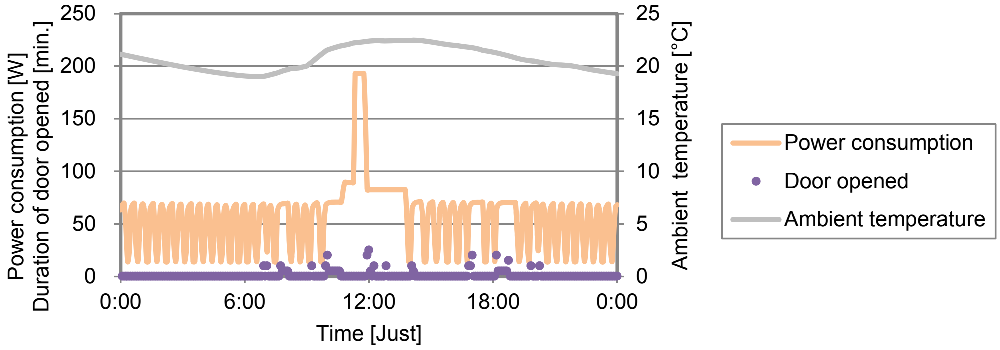

Figure 13: Daily variations of power consumption for Case 1, intermediate season

Table 8 compares annual power consumption of the refrigerator for three cases. In Case 2, in which door openings were excluded, the annual power consumption decreased by 26.0 kWh (4.9 %), as compared with Case 1. This is because the heat transfer through air displacement caused by door openings was reduced. However, in Case 3, in which the ambient air was air-conditioned, the annual power consumption increased by 15.0 kWh (2.9 %), as compared with Case 1. If the ambient air was air-conditioned, the power consumption of the refrigerator decreased in summer, whereas it increased in winter, becauuse the heat exchange rate at the condenser and the heat transfer rate through the cabinet walls were affected by the ambient temperature (see Figure 14). In particular, when the daily average outside temperature was below 17 °C or above 28 °C, there was a distinct difference between Case 1 and Case 3, as Figure 15 shows. In Case 3, the power consumption remained stable within that range of outside temperatures, because the ambient temperature was controlled by the heating or cooling system in the presence of occupants.

Table 8: Comparison of the calculated annual power consumption

Calculation Setup			Annual power consumption [kWh]	Difference from Case 1	
No.	Door opening	Air conditioning		[kWh]	[%]
Case 1	✓		527.4	-	-
Case 2			501.4	-26.0	-4.9
Case 3	✓	✓	542.4	15.0	2.9

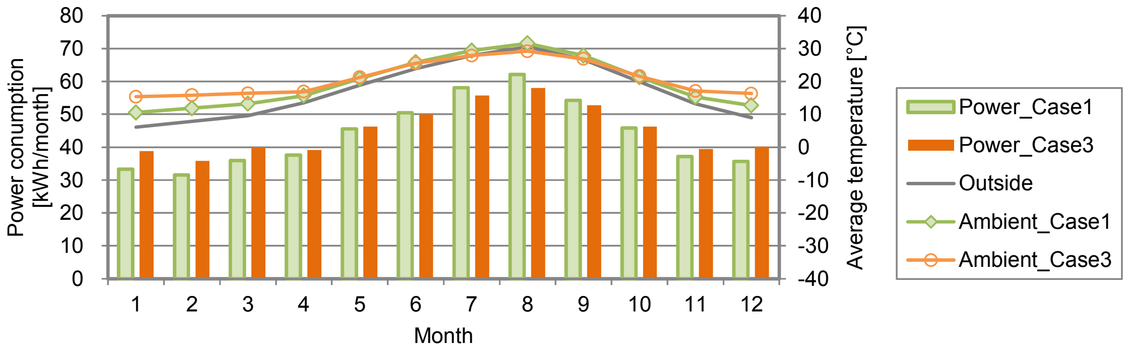

Figure 14: Monthly power consumption and ambient temperature in Case 1 and Case 3

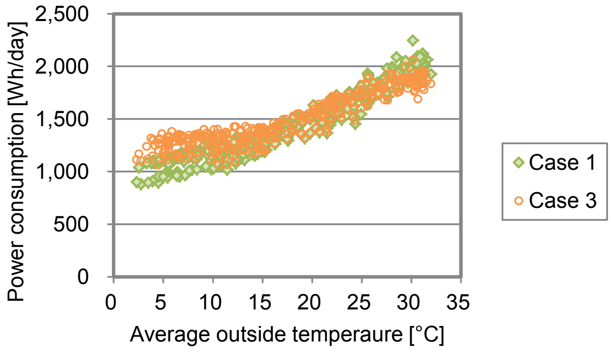

Figure 15: Daily power consumption at a given daily average outside temperature

Conclusion

The simulation model was proposed for the power consumption of a refrigerator, considering the effect of door openings and variations in ambient temperature. Comparisons with experiment show that the model has some problems in predicting the working state of the compressor; however, the total power consumption over twelve hours estimated by the model was close to the experimental value. The model was successful in simulating changes in working modes and increases in compressor runtimes in response to door openings. Moreover, the model predicted that annual power consumption could increase if the refrigerator operates in an air-conditioned room.

A refrigerator constantly imposes heat load on the surrounding room by exchanging heat at the condenser and by consuming electric power. The next step in this study is to improve the model and combine that model with the building simulation model.

Preferences

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Nomenclature

- C thermal capacity [J/K]
- c regression coefficient [-]
- C_p isopiestic specific heat (= 1005) [J/kg·K]
- E power consumption [W]
- g gravity [m/s^2]
- h enthalpy [J/kg]
- h_c height from a floor to the center of an opening (= 1.45) [m]
- N_k compressor speed [Hz]
- Q_c condenser heat transfer rate [W]
- Q_e evaporator cooling capacity [W]
- Q_H heat emission (= 0.0) [W]
- T temperature [°C]
- T_{off} temperature at which the standby mode starts (= -5.28) [°C]
- $T_{on,f}$ temperature at which the freezing mode starts (= -5.01) [°C]
- $T_{on,r}$ temperature at which the refrigerating and freezing mode starts [°C]
- T_{set} temperature set point of compartment [°C]
- t calculation time step [sec]
- t_f elapsed time after the freezing mode starts [sec]
- t_r elapsed time after the refrigerating and freezing mode starts [sec]
- $t_{r,end}$ total runtime of the refrigerating mode [sec]
- UA thermal conductance [W/K]
- V_a displaced air flow rate [m^3/s]
- V_k compressor swept volume rate (= 10.17×10^{-6}) [m^3]
- v_1 specific volume [m^3/kg]
- W_k isentropic compression work [W]
- αA equivalent opening area (= 0.0545) [m^2]
- Δp pressure difference [Pa]
- ΔT_{sup} degree of superheating (= 5.0) [°C]
- Δt calculation interval [sec]
- Δt_{def} interval time of defrosting (= 50839) [sec]
- Δt_{heater} duration of heater working [sec]
- Δt_{post} duration of post-cooling [sec]
- Δt_{pre} duration of pre-cooling [sec]
- η_g compressor overall efficiency (= 1.0)[-]
- η_v compressor volumetric efficiency (= 0.7) [-]
- ρ_a air density at the temperature of 0 °C (=1.293) [kg/m^3]
- ρ air density [kg/m^3]

Subscripts

- amb ambient
- c condenser, condensing
- cab cabinet
- com compartment
- e evaporator, evaporating
- f freezing mode
- $heater$ heater working
- i inside
- k compressor
- o outside
- pre pre-cooling
- $post$ post-cooling
- r refrigerating and freezing mode
- s steady state
- sat saturation
- sup refrigerant superheating

$T_*(0)$

$T_{*,s}$

c_*

T_1 T_2 T_3 T_e T_c T_{amb}

$T_e(t_{r,end})$

C_{cab} C_{com} UA_o UA_i

$N_{k,1}$ $N_{k,2}$ $N_{k,3}$ $N_{k,i}$ $i=1$ $i=2$ $i=3$ $i=4$ $i>4$ $T_{amb}-T_{com}$

$c_{3,*}$ $c_{4,*}$ $c_{5,*}$ $c_{6,*}$

$T_{amb}<30$ $T_{amb}>=30$ $T_{amb}<20$ $T_{amb}>=20$

E_{pre} E_{heater} E_{post}

Techno-economic analysis for introduction of superefficient refrigerators in India

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Abstract

Energy performance improvements in appliances and equipments are essential elements in any government's portfolio of energy efficiency and climate change mitigation programs. The Indian Standards and Labeling (S&L) program for appliances and equipment has been implemented since 2006 by the Bureau of Energy Efficiency (BEE). At present, star rating on a scale of 1 (least energy efficient) to 5 (most energy efficient) is mandatory for four products including frost free refrigerators. The S&L program also includes a strategy of *ratcheting* that is increasing the stringency of both standard and labels every few years for appliances. While revision of standards eliminates less efficient products from the market, they also provide manufacturers to improve efficiency for getting a better star rating. However, increasing efficiency also increases prices and creates a price barrier for consumers.

On the other hand a technology push through the introduction of super-efficient appliances (SEAs) increases the average efficiency in the market and can guide fixing of energy performance standards. In the case of refrigerators there is still a gap between efficiency of a 5-star refrigerator and the best available technology globally; average energy consumption of currently available BEE 5-star models is 26% more than ENERGY STAR© model of same capacity in the US.

Presently, achieving super-efficiency is not on the agenda of Indian refrigerator manufacturers because of two main barriers: first, is the uncertainty regarding market demand for super-efficient refrigerators and second is the uncertainty about cost-effectiveness of manufacturing high-efficiency models. In the present paper, we explored the introduction of super-efficient refrigerators in the India through a techno-economic analysis of commercially available technology options that improve energy performance of refrigerators. Based on literature review and consultations with technical experts of leading refrigerator manufacturers, we compiled a list of design options most feasible for bringing energy efficiency improvements over the baseline. Based on the efficiency improvements and associated incremental manufacturing costs, cost-efficiency curves were generated to understand their relationship. The impact on consumers due to the increase in purchase price of more efficient or super-efficient refrigerators was also evaluated through a Life cycle Costs (LCC) and Payback period analysis. Findings from this study will be useful in indicating the maximum efficiency levels that can be achieved cost effectively using commercially available efficient technologies. This analysis will also help in designing incentive mechanisms for accelerating and commercializing super-efficient technologies so that high cost of very efficient or super-efficient appliances does not become a barrier.

Keywords: Superefficient appliances, refrigerators, efficiency, cost-efficiency curves, payback period, technology options

Introduction

Energy efficiency is rapidly becoming a key policy tool all over the world to meet the substantial growth in energy demand. According to the International Energy Agency [1] 71% of the global emissions reductions would come from energy efficiency improvements in 2020 and 38% by 2050. The mitigation potential of energy efficiency in most sectors can be realized by policies that are designed to encourage the purchase of energy efficient appliances and equipment. By all accounts, programs on energy efficiency are among the least cost options which provide positive returns to government, energy consumers and the environment.

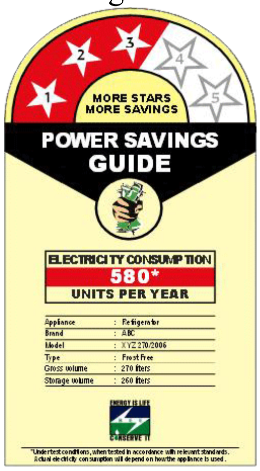
Amongst all regulatory and policy instruments, energy performance standards for energy consuming products are the easiest to implement and have the highest potential to achieve energy savings targets in a short span of time. Globally, implementation of energy performance standards that prescribe either minimum efficiencies or average efficiencies that manufacturers must achieve in their products have helped bring about major improvements in the energy efficiency of home appliances like refrigerators.

In all homes either in the developed or developing world, a refrigerator runs for 365 days a year and almost the whole day. In the US, Minimum Energy Performance Standards (MEPS) for residential refrigerators and freezers were first introduced in 1990 and subsequently revised in 1993 and 2001. A decline in energy consumption by 20% with each revision indicated that these efficiency gains were driven by stringent MEPS that encouraged manufacturers to innovate and design more efficient products. Between 1980 and 2001, the average energy consumption of refrigerators in US declined by 60%. In UK too, the energy consumption of domestic refrigerators and freezers declined by 20-25% between 1989 and 2000 when energy label for refrigerators and freezers was introduced in 1995 [2]

Programs that introduce and implement energy performance standards and energy labeling for energy consuming appliances and equipment, either through voluntary or mandatory compliance, are commonly referred to as Standards and Labeling(S&L) programs. These programs aim to remove inefficient products from the market and promote development of cost-effective energy efficient products.

In India, the Energy Conservation (EC) Act, 2001 identified S&L as a major program area for improving energy efficiency in the residential, commercial, industrial and agricultural sectors and designated the Bureau of Energy Efficiency (BEE) for implementing the provisions of the EC Act. The Indian S&L program comprises implementation of MEPS and 'Star' labeling of energy products on a scale of 1 to 5 in order of increasing efficiency (Figure 3). The star label on products is aimed at helping consumers make energy efficient purchases. For household appliances labeling was first introduced in 2006 on a voluntary basis for refrigerators. In India there are primarily two categories of refrigerators:

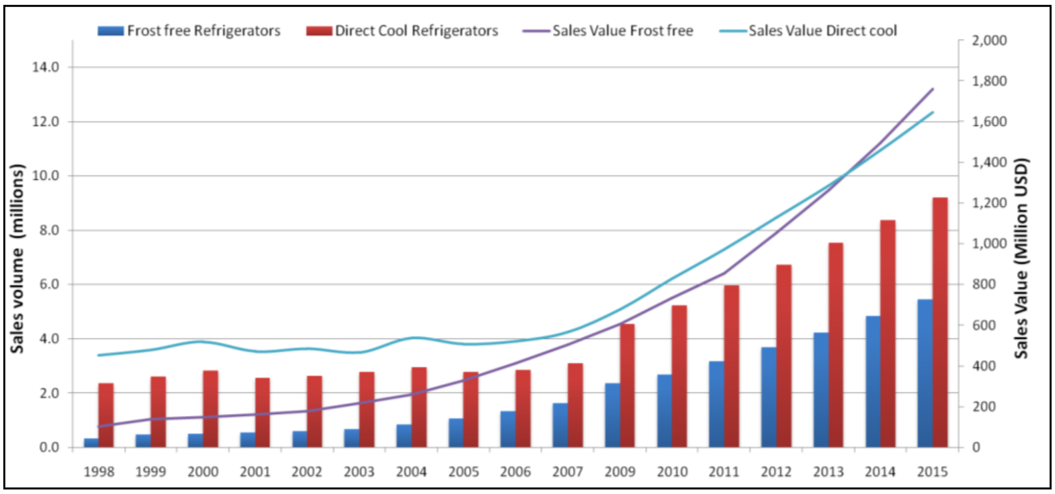
Figure 1: Sample BEE 3-star label for refrigerators



- **Frost free (FF) refrigerators**: These refrigerators come with either two or three doors. Cooling in these refrigerators is by forced air circulation which leads to automatic frosting of the unit. The gross volume of Frost Free models ranges from 200 litres to 600 litres.
- **Direct Cool (DC) Refrigerators**: These are single door refrigerators where the upper portion of the unit houses the freezer, the middle portion is the refrigerator and the bottom portion is normally used for storing vegetables. In a Direct Cool refrigerator, cooling is obtained by natural convection only. These refrigerators require manual defrosting of the frost accumulated in the freezer. Storage capacities of Direct Cool refrigerators range from 50 litres to 300 litres

Historically, DC refrigerators have dominated the refrigerator market and had a 75% market share in 2010-11. However, market size of larger FF refrigerators is also increasing gradually (Figure 2).

Figure 2: Sales volume and sales value of FF and DC refrigerators



Source: Euromonitor, 2012

Foreseeing the changing market conditions, BEE declared mandatory star labeling for FF refrigerators in January 2010. BEE is also considering the same declaration for DC refrigerators in July 2016.

Market transformation of energy efficient refrigerators

Table1 shows the market share of star labeled refrigerators from 2007-10. It can be observed that, when star labeling for refrigerators was first introduced in 2006 by BEE, no refrigerator model was a 1 star and 2-star labeled models also had negligible market share. However, the total market share of 5-star labeled refrigerators had increased from 0.20% in 2007-08 to 58.09% in 2010-11 while that of 4-star labeled refrigerators declined from 76.69% in 2007-08 to 20.63% in 2010-11. This indicates a gradual market shift from less efficient refrigerator models to more efficient refrigerators.

Category wise market penetration of star labeled refrigerators shows similar results. In the FF segment, production of 5-star refrigerators was very low till 2008-09 after which there was a surge in production and a 130% increased from 6474 units in 2008-09 to 844,791 units in 2009-10. Market share of 5-star FF refrigerators has increased from 0.5% to 58.1% and together the more efficient 4 and 5-star refrigerators had almost 80% market share in 2010-11. For DC category also, market has gradually moved towards 5-star, with 56.8% market share in 2010-11 compared to just 0.1% in 2008-09.

Table 1: Market share of star-labelled refrigerators

Star category	Market share (%)											
	2008-09			2008-09			2009-10			2010-11		
	DC	FF	Total	DC	FF	Total	DC	FF	Total	DC	FF	Total
1 star	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0
2 star	0.5	0.0	0.3	0.2	0.0	0.1	0.2	0.0	0.1	0.1	0.0	0.1
3 star	24.3	19.1	23	14.7	13.4	14.4	24.5	10.9	21.4	23.4	12.8	21.2
4 star	75.2	80.4	76.7	77.2	86.2	79.8	29.4	41.3	32.1	19.7	24.3	20.6
5 star	0.1	0.5	0.2	7.9	0.4	5.7	46.0	47.8	46.4	56.8	62.9	58.1

(Source: BEE)

Mapping energy performance of Indian refrigerators on international standards

Refrigeration appliances are perhaps the most regulated products globally with respect to energy efficiency and yet, test procedures for these appliances are least harmonized with most complex and diverse range of national and regional test procedures used globally. This is also because energy consumption of refrigerators is affected by climatic and ambient temperature conditions in addition to lifestyle which vary considerably by the region. This makes international comparisons of energy performance of refrigerators challenging.

Many countries have programs for energy labelling and use different methods for determining energy efficiency standards for electrical equipment. The MEPS system is used in many countries like the US, Australia and India under which all efficiency levels of energy consuming products must not exceed certain standard value, which is the minimum efficiency. The second method is *class- average standard value system,* under which the average efficiency of all products covered in this system should exceed standard value. This system was used in Japan until 1999, when top runner standards were introduced. The Top Runner standards used a maximum standard value system which uses a base value of the product with the highest energy efficiency available in the market at the time of standard setting process and sets standard values by considering potential technological improvements added as efficiency improvements[1].

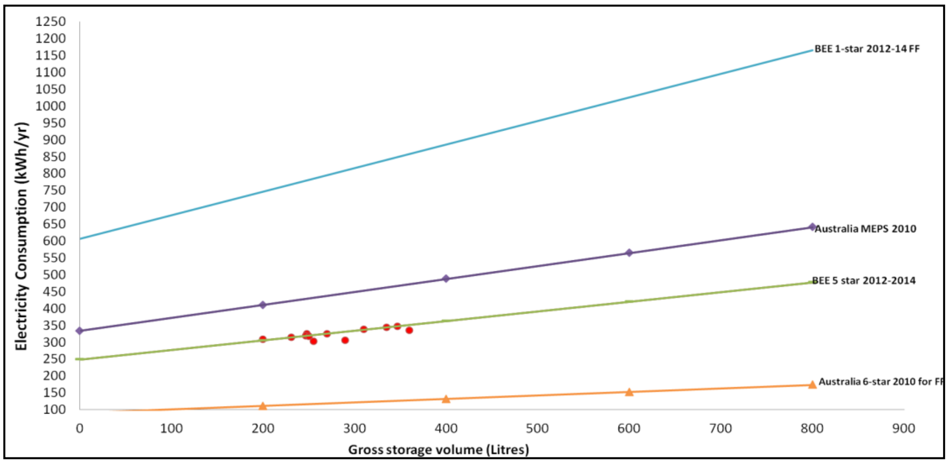
The US Department of Energy's (US DOE) Appliances and Commercial Equipment Standards Program is managed by the Office of Energy Efficiency and Renewable Energy (EERE), which develops and announces test procedures and prescribes mandatory MEPS for consumer appliances and commercial equipment required under the National Appliance Energy Conservation Act (NAECA, 1987). Under NAECA standards for residential refrigerators, refrigerator-freezers and freezer were first announced in 1989 which were revised in 1997 and 2007. The next revisions are to be implemented in July 2014. Besides, there is also the US Environment Protection Agency's (EPA) voluntary labelling program "Energy Star" under which energy star label is given to energy consuming products that are at least 20% more efficient than the existing NAECA standard. In Japan, the Top Runner Program had resulted in an improvement of energy efficiency levels by 55.2% between 1998 and 2004.

Australia also has a standards and labeling program similar to India for nine categories of refrigeration appliances. India's test standards for refrigerators have been derived from Australia (AS/NZS 4474). Since both climatic conditions and consumer preferences are similar between Australia and India, it will be logical to benchmark energy performance of refrigerators in India (both DC and FF) against standards in Australia

Figure 3 shows comparison of energy performance standards of Australia with India for FF refrigerators. Energy consumption of frost free refrigerators available in the Indian market today has also been mapped on the same graph to illustrate their energy performance compared to Australian standards. The Highest energy performance standard or HEPS for FF refrigerators in India is BEE 5-star while the MEPS is BEE 1-star. In Australia, the HEPS is defined by the 6-star label and MEPS by the 1-star label. Comparing the MEPS and HEPS of India and Australia for FF refrigerators (group 5T), it can be observed that the Indian MEPS lags significantly behind the Australian MEPS, the difference being as high as 45%.

Comparing the HEPS in FF segment, the Australian energy performance thresholds for 6-star top-mounted refrigerators are 65% stronger than that for BEE 5-star.

Figure 3: Comparison of Indian standards for FF refrigerators with Australian standards



BEE's star labeling plan for refrigerators

[1]METI, 2010. Top Runner Program: Developing the world's most efficient appliances

In India, the BEE declares mandatory energy labeling of products through a notification in the official gazette. For FF refrigerators, such a notification was released on January 12, 2009 instructing manufacturers to compulsorily affix star labels on their FF products from January 2010 onwards. In parallel, BEE had also released energy labeling requirements for FF and DC refrigerators in schedules 1 and 5A respectively in 2006. These schedules informed manufacturers about time bound revisions in the energy performance standards of refrigerators up till December 2015.
Released much in advance, the schedules were aimed at giving manufacturers sufficient preparatory time for moving to higher energy efficiency in the future. However, keeping in view changing market conditions, BEE also convenes technical committee meetings before a forthcoming revision and seeks manufacturer inputs on energy performance thresholds prescribed. Being a mandatory product, revisions in energy performance thresholds for FF refrigerators have so far been on time.
The same cannot be said for DC refrigerators though. The voluntary nature of the labeling scheme for this product category has led to frequent delays in the plan envisaged and prescribed by BEE in the schedule. For FF refrigerators, the rating plan was revised for the first time since 2006 in January 2010 and for the second time in January 2012. This will be followed by the third revision in January 2014. With each revision since 2006, there has been a 20% ratcheting of standards. The next revision in 2014 aims at a 40% jump from the current levels.
For DC refrigerators, the rating plan has not been revised since 2006. Recent developments have indicated at a next revision for DC category in July 2014, followed by a mandatory labeling and threshold revision in January 2016. Thus for both categories of refrigerators, BEE does not have a plan for revising energy performance thresholds beyond 2016.

Need for techno-economic analysis

Prior to launching the S&L program for refrigerators in 2006, BEE had conducted several studies and collected manufacturer data to decide and fix energy performance thresholds for refrigerators in the coming few years. Similar studies need to be undertaken by BEE well in advance to make informed decisions on fixing energy performance standards that reflect changing market and technology conditions. Most countries undertake techno-economic analysis to seek answers to the following questions:

- *Determining the best target efficiency level for standards*: Considering that technologies for improving appliance efficiency are evolving continuously over the last few decades, there is a certain achievable limit to energy performance that can be reached. A techno-economic analysis helps in estimating the best target efficiency level through the introduction of the best available technology
- *How will the technology intervention(s) effect consumers and manufacturers financially*? It is a well-established fact that all new technological interventions in existing products have a cost associated with them. In general, it has been observed that more efficient products are more expensive than those that are relatively less efficient. By conducting a techno-economic analysis, the impact on the manufacturer as an increase in manufacturing cost and on the consumer through an increase in purchase cost can be determined
- *Impacts on national energy consumption and GHG emissions*: A more efficient product or super-efficient appliance will result in reduction in national energy consumption and consequently lead to a decline in net GHG emissions

A potential drawback of techno-economic analysis is that the efficiency and cost of a project model may be subject to significant uncertainty since it has not been mass produced [3]. Projecting prices of models that are significantly more efficient than existing models is difficult and subject to uncertainties and variations (over time and for models of differing efficiencies). Also typically manufacturers do not perform a rather theoretical techno-economic analysis for deriving at efficiency improvements. In most cases, manufacturers try out different combinations of options on the field, test the energy performance of the model and evaluate whether this meets prescribed standards and finally based on cost estimates mass produce the new improved model.
However despite these limitations, a techno-economic analysis helps policy makers in making a broad assessment of efficiency possibilities and cost implications.
In the present paper, we have presented the findings from a techno-economic analysis for determining efficiency levels economically feasible for refrigerators in India. A consumer-impact analysis was also done to estimate payback period, cost of conserved energy.
Under, the Super-Efficient Equipment Program (SEEP) BEE plans to offer manufacturers incentives to produce superefficient appliances that are 30-50% more efficient than the most efficient ones available in the market. Findings from this study will be useful in indicating the maximum efficiency

levels that can be achieved cost effectively using commercially available efficient technologies. This analysis will also help in designing incentive mechanisms for accelerating and commercializing super-efficient technologies so that high cost of the Super-efficient appliances (SEA) does not become a barrier

Methodology

We conducted a techno-economic analysis of commercially available technology options for improving the energy efficiency of Indian refrigerators. Described below is the approach followed for conducting the techno-economic analysis.

Selection of baseline units. Selection of the baseline unit is the starting point for analyzing design options for improving energy efficiency. The baseline model selected should be representative of the class. In the previous sections we have described how market for refrigerators has transformed and 5-star labeled refrigerators account for more than 50% of the total refrigerator market for both categories (DC and FF). Therefore 5-star labeled unit was selected as the baseline for additional efficiency improvements. Also, based on volume-wise market share data obtained from [4] for DC refrigerators, a 170 litre model was selected as baseline and for FF refrigerators a 220 litre model was selected.

Selection of design options for improving refrigerator efficiency: Based on a comprehensive review of similar studies done by agencies like US DOE [5] European Ecodesign Initiative [6] and Japan's Top Runner Program [7], a list of design options for improving energy efficiency of both frost free and direct cool type of refrigerators was prepared. The different design modifications were listed under the following components of refrigerator design:

- Insulation
- Improvements in design of door gasket
- Anti-sweat heater
- Heat exchanger (condenser and evaporator)
- Fan and fan motors
- Compressor
- Expansion valve
- Defrost system
- Optimization of system controls
- Alternative refrigeration cycles
- Alternative refrigeration systems
- Other technologies (not mentioned under any of the above categories)

The list of options compiled and discussed with Indian manufacturers did not take into account global experience and evaluation of these options. This was because, Indian conditions are unique and while some options could have been rejected in other studies they might be feasible and implementable for Indian refrigerators. Therefore, a complete list of design options was taken to the manufacturers.

Consultations with manufacturers: The initial list of design options was prepared based on review of studies done globally on improving energy performance standards for refrigerators. Meetings were conducted with four leading refrigerator manufacturers for discussing these options. Two of these manufacturers are domestic and while the other two are international players that together comprise more than 50% of the market. All the consulted manufacturers have refrigerator manufacturing facilities in India. For getting the desired inputs from manufacturers on the identified design options, a spread-sheet based questionnaire was prepared for manufacturers. The spread sheet served as a database for compiling information from manufacturers under the following categories:

- *Feasibility or implement ability*: For each of the identified design option, the feasibility of implementing the option in India and the time period for bringing the technology to India was asked from consulting manufacturers
- *Applicability*: Applicability of the design option to Direct cool or/and frost free refrigerators was asked
- *Improvement in energy efficiency (%):* The improvement in the energy efficiency of the baseline refrigerator models relative to the baseline BEE 5-star model was needed from

manufacturers. Consulted experts were asked to provide an estimate of an improvement in energy efficiency with the introduction of each design option under each component category

- *Incremental manufacturing cost (INR):* Each change in design of the component has a cost associated with it. This cost is reflective of the manufacturing cost (if the component is manufactured in India) or the import cost (if component is imported). The incremental cost to manufacture relative to baseline of 5-star was asked
- *Increase in consumer price (INR):* Manufacturers pass on any increase in the manufacturing cost to consumer. Therefore any change in the price of the product due to the introduction of a design option in the baseline model was captured through the questionnaire
- *Any other option*: Manufacturers were asked to provide information about any other option that was not included in the original list, which they felt could contribute to energy use reduction in a refrigerator

Consulted experts were encouraged to share more information with respect to the challenges faced by manufacturers in improving energy performance for refrigerators in India and their general perception about how these challenges can be overcome was also discussed. It must be noted that estimates given by manufacturers on the incremental costs to producer and consumer are indicative. High estimates can often be provided for more efficient technology since the technology has not been imported or manufactured in India, in which case the estimates are subject to changes in exchange rates, global component/commodity prices and may change due to economies of scale.

Table 2: List of design options compiled and discussed with Indian manufacturers

Component	Design Option
1. Insulation	Increased insulation thickness
	improved resistivity of insulation
	Increase in density of PU foam density
	improved thermal properties of insulation foam
	Vacuum-insulated panels in the model door
2. Design of door gasket	Double door gaskets
	improved door face frame
	gas filled panels
3. Anti-sweat heater	Electronic control of hot gas discharge tube embedded around freezer door frame
	Optimal positioning and design of electric anti-sweat heaters of freezer doors
	Electric anti sweat heater sizing
	Variable anti-sweat heating
	Electric heater controls
4. Heat exchanger (Condenser and Evaporator)	Improved heat exchange through use of enhanced fins/tubes of evaporator and condenser
	Increase in area of condenser
	Increase in area of evaporator
	Incorporating forced convection heat exchangers
5. Fan and fan motors	Use of more efficient fan motors like Brushless DC fan motors
	Use of phase-change materials integrated into heat exchanger to increase effective thermal capacity
	Phase-change materials+ optimization of the compressor on/off cycling
6. Compressor	Variable speed compressors/variable capacity compressors
	Linear compressors
	Alternative technologies to reciprocating compressors
7. Expansion Valve valves)	Use of fluid control or solenoid valves
8. Defrost system	Reduced energy for automatic defrost
	Use of adaptive defrost system
	Condenser hot gas defrost system

9. System controls	Electronic temperature controls
	Air distribution control
	improved electric controls with VCCs
10. Alternative Refrigeration cycles	Lorenz Meutner cycle
	Dual loop system
	Two-stage system
11. Alternative Refrigeration systems	Stirling cycle,
	thermo-electric refrigeration
	thermo-acoustic
12. Other Technologies	Alternative refrigerants
	Change in component location

Generating cost-efficiency curves: Based on the inputs from consulted manufacturers, cost-efficiency curves were developed, indicating the relationship between incremental manufacturing costs (INR) and the percentage efficiency improvements associated with each design option.

Estimating Life cycle costs (LCC): To assess the impact of a new more efficient product on the cost to the consumer during the lifetime of the product, Life Cycle Cost is calculated. The US DOE calculates LCC as the sum of the purchase cost and the annual operating costs discounted over the lifetime of the product and calculated based on the equation below:

$$LCC = PC + \sum_{1}^{N} \frac{OC}{(1-r)^t}$$

Where,
PC= Product Cost
OC= Annual operating cost of the product
r= discount rate
t= lifetime of the appliance

The annual operating cost of the product reflects the savings accruing to the consumer on account of the higher efficiency and is equal to the product of the Unit electricity Cost or tariff (Rs/kWh) and the energy consumption of the product. It is expected that the Life cycle cost of a more efficient product is likely to be lower than that of a less efficient product because of lowered operating costs associated with the former. The monetary savings to the consumer over the lifetime of the appliance have to also be discounted by using a constant discount factor r. Since consumers value immediate savings more than future savings, the time value of money is typically accounted for by discounting future savings using a discount rate [8].
For this study, LCC for each design option was calculated as:

LCC= Product Cost + NPV of operational costs, discounted over lifetime of the product

Consumer impacts analysis: to understand the cost implications of purchasing more efficient refrigerators from consumer perspective, payback period and benefit-cost ratio.

- **Payback period:** The Payback period is an often used number when estimating the time period of returns from an initial investment in any product or service. As discussed in the previous sections, energy efficient appliances cost more than lesser efficient appliances. Similarly, introduction of a super-efficient refrigerator incorporating one design option or a combination of design operations has high initial investments associated with it. A payback period is the number of years after which cumulative operating cost savings exceed the incremental equipment cost. The incremental equipment cost is additional to the cost paid for by the consumer for a lesser efficient model:

  Payback Period= ΔIC/ ΔOC

  Where **ΔIC**is the purchase cost difference between a more efficient and less efficient product and **ΔOC**is the difference in operating costs of a more efficient and less efficient product.
- **Cost of Conserved Energy (CCE):** the cost of conserved energy divides the incremental investment cost by the annual energy saved (INR/kWh)

The parameters used for calculating payback period, CCE and Life cycle cost (LCC) are given below:

Product cost: Manufacturer consultations provided information about the change in product costs associated with specific design options. We assumed that these incremental values over the cost of the baseline of BEE 5-star was inclusive of the retail mark-up. We used market data[2] collected from trade magazines to estimate the average price of 180Litre 5-star Direct cool refrigerator and a 220Litre 5-star frost free refrigerator.

Appliance lifetime (t): The typical lifetime of a refrigerator is 10 years [4]. However our experience conducting market research in North Delhi on refrigerator replacement cycle indicated that vintage of refrigerators owned range from 6 years to 20 years. In another study [8] assumed a refrigerator lifetime of 15 years for Indian refrigerators. The feedback from manufacturers on refrigerator lifetime was also approximately 7 to 10 years. We have therefore used an average lifetime of 10 years for refrigerators for doing the LCC analysis.

Unit electricity cost (UEC): UEC used for payback period analysis was based on published tariffs from the ARR of Delhi based private distribution company[3] assuming that a domestic consumer using a refrigerator will fall in the tariff slab corresponding to 100 kWh/month would give a national average rate of INR 4.5/kWh (based on domestic sales). Using national average tariff rate from 2009-10 is a conservative assumption, since higher electricity prices at present and in the future will yield larger monetary savings to the consumer. To refine payback period and BCR estimates for the design options, a year on year tariff escalation rate of 5% for determining the NPV of operational costs over the lifetime of the product was also used. The escalation rate is based on average long term inflation rate.

Discounting factor (r): Calculating the discount factor for discounting operational energy savings to consumer overtime is challenging. Discounting factor used by [9] for estimating potential energy savings from improved energy efficiency of refrigerators in India was 15% for domestic consumers. It was based on the rate used by utilities for their investment in Demand Side Management or efficiency programs. In India, very few utilities have guidelines for estimating cost-effectiveness of DSM interventions. Maharashtra Electricity Regulator Commission (MERC) has published Regulations for DSM measures and Program's Cost Effectiveness Assessment in 2010. In the present study we have used MERC's prescribed discounting factor for participants (consumers) in a DSM program, which is 13%.

Results

(1) Design options for efficiency improvements in Indian refrigerators

As described above, four leading manufacturers were approached with a list of design options studied globally for bringing about further energy improvements in existing domestic refrigeration appliances. Not all design options discussed with the manufacturers were found feasible for Indian conditions. The Indian scenario as described by one of the experts is different from rest of the world; it is characterized by diverse climatic conditions in different parts of the country, differing quality and reliability of supplied power and voltage fluctuations, differing ambient conditions (where in many domestic households refrigerators are kept in warm kitchens). These factors have prompted Indian manufacturers to over-design components used in Indian refrigerators to enhance their ability to withstand varied conditions.
Table 3 shows the final list of design options, for which the consulted experts provided complete information (1) % improvement in efficiency over baseline (2) incremental costs to manufacturer and (3) cost to consumer.

[2] TV Veopar Journal, January 2013 issue
[3] Tata Power Delhi Distribution Limited: www.tppdl.com

Table 3: Final list of design options for improving efficiency of Indian refrigerators

Component	Design Option	Energy efficiency improvement over BEE 5-star	Time period for implementation	Incremental Manufacturing Costs (INR)
Insulation	*Increased insulation thickness (8 to 10 mm)*	10%	3-5 months	Rs.400/- approx
	Increase in density of PU foam	4 ~ 5%	1 month	Rs.250/-
	Vacuum-insulated panels in the model door	10 ~ 12%	3-5 months	Rs.400 ~ 500/-
Heat Exchanger Improvements	*Increase in area of condenser (20%)*	5-6%	2-3 months	Rs.150 ~ 180/-
	Increase in area of evaporator (by 20%)	5-6%	2-3 months	Rs.150 ~ 180/-
	Incorporating forced convection heat exchangers	5-6%	4-5 months	Rs.150 ~ 180/-
Fan Motors	*Brushless DC motors*	2-3%	4-5 months	Rs. 300
Compressor	*Variable speed compressors/variable capacity compressors*	25 to 30%	1- 1.5 years	Rs.2500 ~ 3000/-
Electronic Controls	*Electronic temperature controls,*	5 to 10%	6- 8 months	Rs.250 ~ 300/-
	air distribution control	5 to 10%	6- 8 months	Rs.250 ~ 300/-

It must be understood, that complete data for all design options was difficult to obtain from the consulted experts. For e.g. for some options even if information with respect to feasibility, time period of implementation and efficiency improvements was available, the cost estimates were not provided by consulted experts. We observed that most technical experts in leading manufacturing companies do not willingly share data on cost estimates since this information is highly confidential. Also, some of the experts consulted confessed to having limited knowledge about costs and efficiency estimates since no prior research has been conducted on these aspects by the Indian refrigerator manufacturing industry. According to one expert, during product development and designing, field technicians experiment with different combinations of design changes in a few components to meet the energy performance standard prescribed by BEE under the star label.

Some options like Variable Speed Compressors have high initial investments associated with their introduction although the efficiency gains are significant (25-30%) while some options like better electronic controls of temperature and air distribution result in 5-10% energy savings at a much lower cost (Rs. 250-300). The time period required for most design options is less than 6 months which is a good indication since it implies that future improvements in energy efficiency of refrigerators will be able to meet BEE targets timely.

(2) Combining options for energy efficiency improvements

As mentioned above, efficiency improvements in refrigerators while designing and development are brought about through a combination of changes in key components. We followed the same logic while arriving at different design options for improving efficiency of baseline BEE 5-star in both Direct cool and Frost free categories of refrigerators.

In the previous sections, alternative insulation technologies like VIPs were discussed. VIPs in the model door alone can lead to 10-12% improvement in the energy performance of BEE 5-star refrigerator. VIPs can also be used in combination with PU foam insulation wherein, VIPs can be fixed in certain critical parts of the refrigerator like the freezer door, near the compressor etc, where better insulation will result in significant reduction in energy consumption of the refrigerator. We therefore identified two cases for design improvements

- **Case 1: Without VIPs:** This combination of design options ruled out the introduction of VIPs in the model door and was focussed on achieving energy efficiency improvements through changes in the existing PU foam insulation, heat exchangers, compressor, fan motors and electronic controls
- **Case 2: With VIPs**: This combination of design options was based on the assumption that assuming that PU foam insulation cannot be used and VIPs replace PU foam insulation in all parts of the refrigerator.

For both the cases, with each successive improvement in % energy efficiency, options were combined and finally cumulative impact of combining options, one step at a time on the energy efficiency was estimated. The design options for direct cool and frost free refrigerators are described below.

Direct cool Refrigerators**:** The final list of design options and the associated energy efficiency improvements and incremental manufacturing costs for direct cool refrigerators is described in tables 4 and 5.

Table 4: Design options under Case 1- Without VIPs for Direct Cool Refrigerators

Design Number	Options	Efficiency Improvement (%)	Incremental Manufacturing Cost (INR)
1	increase in area of condenser by 20%	5%	170
2	1+ increase in area of evaporators by 20%	10%	340
3	2+increase in density of PU foam	15%	590
4	3+ incorporating forced convection heat exchangers	20%	760
5	4+ increase in insulation thickness	28%	1160
6	5+ variable speed compressors	53%	4160

It must be noted that the efficiency improvements associated with related options cannot be summed up. Therefore, and any impact on the energy efficiency cumulatively between related options needs to be discounted to account for any reductions that may occur when related options are combined. For e.g. although when individually implemented, increasing the thickness of PU foam and increasing the density of PU foam result in 10% and 5% energy efficiency improvement, when combined together, the resultant energy efficiency improvement will not be 10%+5% or 15%; in fact since both are related to insulation improvements, the efficiency improvement will be discounted by a small factor. Based on experts consulted, this discounting percentage ranged from 5% to 10%.

Table 5: Design options under Case 2- With VIPs for Direct cool refrigerators

Design Number	Options	Efficiency Improvement (%)	Incremental Manufacturing Cost (INR)
1	Vacuum-insulated panels in the model door	12%	500
2	1+ increase in area of condenser by 20%	18%	680
3	2+increase in area of evaporator by 20%	22%	860
4	3+ incorporating forced convection heat exchangers	26%	1020
5	3+ variable speed compressors	52%	3860

Frost free refrigerators**:** The final list of design options and the associated energy efficiency improvements and incremental manufacturing costs for direct cool refrigerators is described in tables 16 and 17

Table 6: Design options under Case 1- Without VIPs for Frost free Refrigerators

Design Number	Options	Efficiency Improvement (%)	Incremental Manufacturing Cost (INR)
1	increase in area of condenser by 20%	5%	170
2	1+ increase in area of evaporators by 20%	10%	340
3	2+increase in density of PU foam	15%	590
4	3+ incorporating forced convection heat exchangers	20%	760
5	4+ BLDC fan motors	23%	1060
6	5+electronic temperature controls	33%	1360
7	6+ air distribution controls	40%	1660
8	7+ increase in insulation thickness	47%	2060
9	8+ Variable speed compressors	70%	4660

Table 7: Design options under Case 2- With VIPs for Frost free refrigerators

Design Number	Options	Efficiency Improvement (%)	Incremental Manufacturing Cost (INR)
1	Vacuum-insulated panels in the model door	12%	500
2	1+BLDC fan motors	15%	800
3	2+increase in area of condenser by 20%	20%	970
4	3+ increase in area of evaporator by 20%	25%	1140
5	4+ incorporating forced convection heat exchangers	28%	1310
6	5+ electronic temperature controls	35%	1580
7	6+ air distribution controls	40%	1830
8	7+VSCs	60%	4830

(3) Cost-efficiency curves

The cost efficiency curves in Figures 4 and 5 for DC refrigerators and in figures 6 and 7 for FF refrigerators show the relationship between incremental manufacturing costs and corresponding efficiency improvement.

In Case 1, for both DC and FF refrigerators, where VIPs have been ruled out as a means for improving energy efficiency, improvements in the existing PU foam insulation through various means like increasing insulation thickness and increasing density of PU foam have been considered. The range of efficiency improvements in this case ranges from 5% to 53% in case of Direct cool refrigerators (Figure 4) and upto 70% for frost free refrigerators (Figure 6). At each stage, cumulative improvements in energy efficiency and the incremental manufacturing cost are calculated. The introduction of Variable Speed Compressors (VSCs) leads to a 23% increase in energy efficiency improvement from 47% to 70% in frost free refrigerators.

It can be observed that in Case 2, through the introduction of VIPs, a 12% improvement in the energy efficiency is possible, this is the first option in this case for both DC and FF refrigerators and has an incremental manufacturing cost of INR 500. There is a steep 60% increase in incremental manufacturing cost with design number 8 when VSCs are added to design number 7 and efficiency improves by 20% for frost free refrigerators (Figure 7)

Figure 4: Cost-efficiency Curve -without VIP (Case 1) for Direct Cool refrigerators

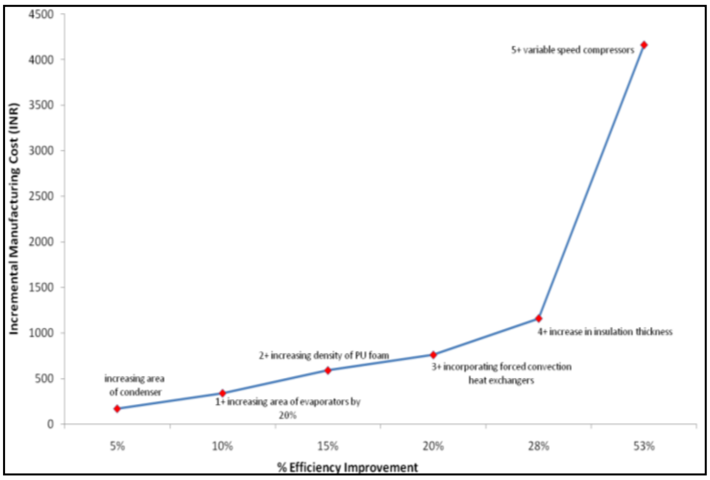


Figure 5: Cost efficiency curve - without VIP (Case 2) for Direct Cool refrigerator

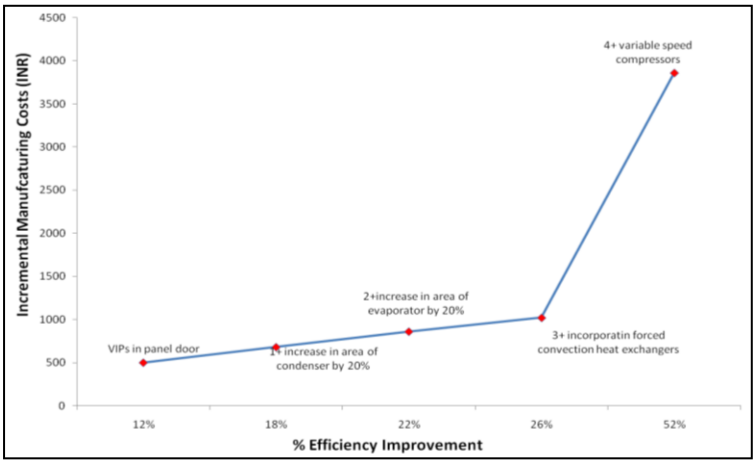


Figure 6: Cost-efficiency Curve -without VIP (Case 1) for Frost free refrigerators

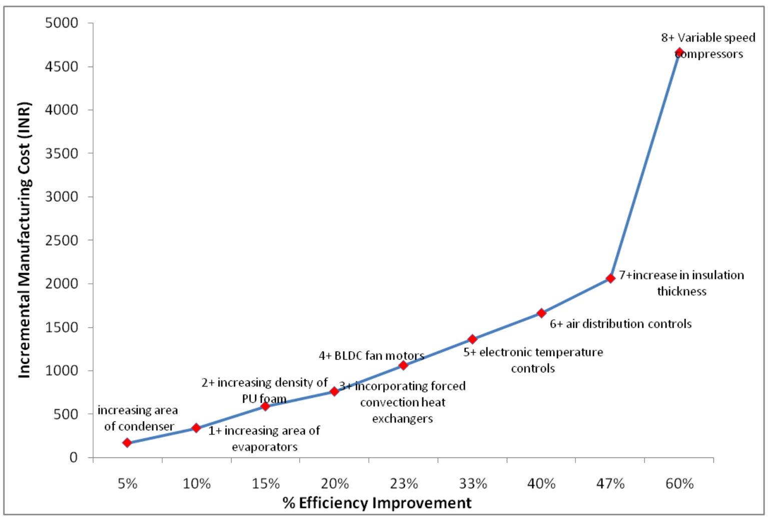
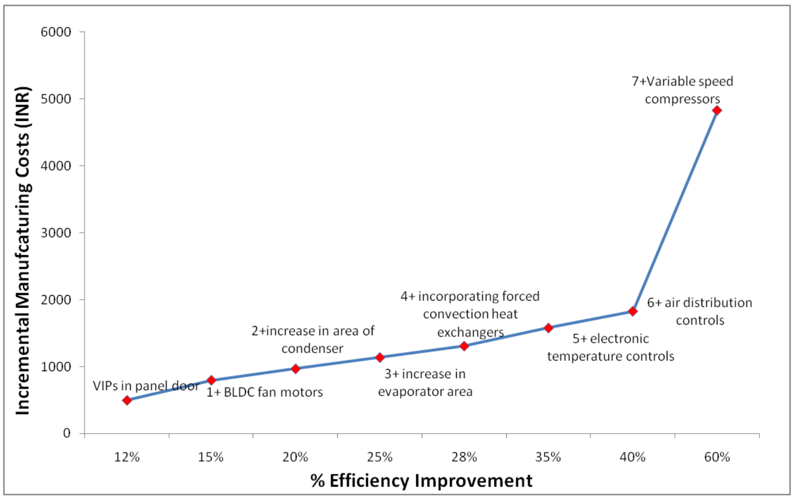


Figure 7: Cost-efficiency Curve without VIP (Case 2) for Frost free refrigerators



(4) LCC and payback period analysis

The Life cycle costs for baseline and the design options under both case 1 and 2 were calculated assuming an appliance lifetime of 10 years and a year on year tariff escalation rate of 5%. These constants were used to calculate the NPV of operational costs of baseline product and improved products over the lifetime of the product discounted at 13%.

The simple payback period of improved product was calculated by dividing the difference in the retail cost of more efficient product and baseline 5-star and the monetary savings from the operation of more efficient product over the baseline. The LCC and Payback period was calculated for all design options and for both cases (case 1 and 2) for DC and FF refrigerators.

Direct Cool Refrigerators

Tables 9 and 10 show the LCC and Payback period associated with each combination of design options under cases 1 and 2 respectively for DC refrigerators. For DC refrigerators, the LCC of the baseline was calculated to be INR 20,585 and the LCC of the option that led to maximum improvement in energy efficiency (design number 6 leading to 53% improvements in case 1) was INR 22,029. This was because the product cost of design number 6 was high. The LCC of this design option exceeded that of the baseline.

However, for all the other design options, with subsequent improvements in the energy efficiency, the LCC reduced since NPV of operational savings associated with improved product decreased over the lifetime of the product. Under case 1, the payback period for all option was less than 5 years, which is lesser then assumed lifetime of 10 years for the product. An improvement in efficiency of up to 28% over the baseline 5-star labelled refrigerator has a payback period of less than 4 years. The CCE varies between INR 13.9/kWh to INR 32/kWh. This indicates that CCE increases with increasing efficiency and cost for conserving each unit of energy is also increasing.

Table 8: Case 1 for 180 L Direct Cool Refrigerators

Design Number	Efficiency improvement over baseline (%)	Annual Energy Consumption (kWh/year)	Annual Operating Costs (INR)	Retail cost of Product (INR)	Payback period (Years)	Life Cycle Costs (INR)	CCE (INR/ kWh)
0	0	245	1103	12,948	0.0	20585	0
1	5%	233	1047	13,220	3.1	20380	13.9
2	10%	221	992	13,492	3.1	20173	13.9
3	15%	208	937	13,892	3.6	20029	16.1
4	20%	196	882	14,164	3.4	19817	15.5
5	28%	176	794	14,644	3.8	19939	16.9
6	53%	115	518	15,124	7.1	22029	32.0

Under case 2, with addition of VIP, the LCC of the design option leading to maximum efficiency improvement i.e. design 5 resulting in 28% improvement in efficiency is higher than the baseline LCC. The payback period of all options except the fifth option was less than 5 years. The CCE varies between INR 17/kWh to INR 56.3/kWh. It can be concluded that case 2 for DC refrigerators, where VIPs are used is not a very cost-effective measure. It hikes the price of the product resulting in much higher payback periods and CCE.

Table 9: Case 2 for 180 L Direct Cool Refrigerators

Design Number	Efficiency improvement over baseline (%)	Annual Energy Consumption (kWh/year)	Annual Operating Costs (INR)	Retail cost of Product (INR)	Payback period (Years)	Life Cycle Costs (INR)	CCE (INR/ kWh)
0	0	245	1103	12948	0	20585	0
1	12%	233	970	13448	3.8	20168	17.0
2	15%	221	937	13628	4.1	20119	18.5
3	20%	208	882	13808	3.9	19917	17.6
4	25%	196	827	13968	3.7	19695	16.7
5	28%	176	794	16808	12.5	22306	56.3

Frost free Refrigerators

Tables 10 and 11 show the LCC and Payback period associated with each combination of design options under cases 1 and 2 respectively for FF refrigerators.

For FF refrigerators, the LCC of the baseline was calculated to be INR 30,695 and the LCC of the option that led to maximum improvement in energy efficiency (design number 9 leading to 70% improvements in case 1) was marginally lower at INR 30,612. For all design options, with subsequent improvements in the energy efficiency, the LCC reduced since NPV of operational savings associated with improved product decreased over the lifetime of the product.

For frost free refrigerators, under case 1, all design options except option 5 and 9 had a payback period less than 5 years. This implies, that design options for improving efficiency of baseline 5-star are cost-effective with small payback time periods. The CCE of options in case 1 range from INR 17.3/kWh to INR 33.8/kWh.

Table 10: Case 1 for 220 L Frost free Refrigerators

Design Number	Efficiency improvement over baseline (%)	Annual Energy Consumption (kWh/year)	Annual Operating Costs (INR)	Retail cost of Product (INR)	Payback period (Years)	Life cycle costs (LCC)	CCE (INR/kWh)
0	0	315	1418	19,925	0.0	30,695	0
1	5%	299	1347	20,197	3.8	30,428	17.3
2	10%	284	1276	20,469	3.8	30,162	17.3
3	15%	268	1205	20,869	4.4	30,023	20.0
4	20%	252	1134	21,141	4.3	29,757	19.3
5	23%	243	1091	21,621	5.2	29,914	23.4
6	33%	211	950	22,101	4.7	30,612	20.9
7	40%	189	851	22,581	4.7	29,043	21.1
8	47%	167	751	23,221	4.9	28,929	22.3
9	70%	95	425	27,381	7.5	30,612	33.8

Even in case 2, all but two options had a payback period of less than 5 years. Comparing cases 1 and 2 for FF refrigerators, it can be concluded that for almost the same level of efficiency improvement (33% in case 1) and 35% in case 2, the payback period is different: 4.7 years for option 6 under case

1 and 5.1 years for option 6 under case 2. This also indicates that the return on investment for VIPs in FF refrigerators is not very lucrative and other simpler, cheaper options should be explored for improving efficiency like use of BLDC fan motors, increasing area of condenser and evaporators, improving electronic controls etc.

Table 11: Case 2 for 220 L Direct Cool Refrigerators

Design Number	Efficiency improvement over baseline (%)	Annual Energy Consumption (kWh/year)	Annual Operating Costs (INR)	Retail cost of Product (INR)	Payback period (Years)	Life cycle costs (LCC)	CCE (INR/kWh)
0	0	315	1418	19,925	0	30,695	0
1	12%	277	1247	20,725	4.7	30,202	21.2
2	15%	268	1205	21,205	6.0	30,359	27.1
3	20%	252	1134	21,477	5.5	30,093	24.6
4	25%	236	1063	21,749	5.1	29,826	23.2
5	28%	227	1021	22,021	5.3	29,775	23.8
6	35%	205	921	22,453	5.1	29,453	22.9
7	40%	189	851	22,853	5.2	29,315	23.2
8	60%	126	567	27,653	9.1	31,009	40.9

Conclusions

The evaluation of efficiency improving design options for direct cool and frost free refrigerators is based completely on manufacturer inputs specifically on the costs of imported technologies and subsequent impact on the overall cost of the product as sold to the end consumer. Therefore, the increase in costs associated with increase in efficiency are strictly indicative and may not accurately represent true market conditions in the future, when these technologies will have to be deployed for meeting stricter energy performance standards (BEE has prescribed a 40% increase in efficiency over present baseline in the revisions that come into effect in 2014). Market dynamics will bring down the costs of these component design modifications in the future, substantially decreasing the pay back periods and costs borne by consumers.

Also, our consultations with manufacturers have indicated that some of the design options evaluated in the study have been introduced by some manufacturers for meeting the revised energy performance standards this year. As one manufacturer confirmed, BLDC fan motors have been used in its 5-star labelled frost free refrigerators launched this year. Advanced technologies like linear compressors have been introduced in premium segment frost free refrigerator models of one brand.

There is therefore no doubt that both incremental manufacturing costs and retail prices will change when manufacturers bring about efficiency improvements using the studied design options in future as they would have the benefit of competitive pricing and economies of scale.

The paper also throws light on costs involved for introducing super-efficient refrigerators in India. These findings will be useful in indicating maximum efficiency levels that can be achieved cost-effectively and pave way for further understanding of incentives requirements for promoting highly efficient refrigerators.

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European Commission
EUR 26660 EN – Joint Research Centre – Institute for Energy and Transport

Title: Proceedings of the 7th International Conference EEDAL 2013 Energy Efficiency in Domestic Appliances and Lighting

Authors: Gueorgui Trenev, Paolo Bertoldi

Luxembourg: Publications Office of the European Union

2014 – 1499 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424

ISBN 978-92-79-38406-6

doi: 10.2790/2313

Abstract:

This book contains the papers presented at the seventh international conference on Energy Efficiency in Domestic Appliances and Lighting. EEDAL'2013 was organised in Coimbra, Portugal in September 2013. This major international conference, which was previously been staged in Florence 1997, Naples 2000, Turin 2003, London 2006, Berlin 2009, Copenhagen 2011 has been very successful in attracting an international community of stakeholders dealing with residential appliances, equipment, metering and lighting (including manufacturers, retailers, consumers, governments, international organisations and agencies, academia and experts) to discuss the progress achieved in technologies, behavioural aspects and policies, and the strategies that need to be implemented to further progress this important work.

Potential readers who may benefit from this book include researchers, engineers, policymakers, and all those who can influence the design, selection, application, and operation of electrical appliances and lighting.

LD-NA-26660-EN-N

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Publications Office

doi: 10.2790/2313

ISBN 978-92-79-38406-6